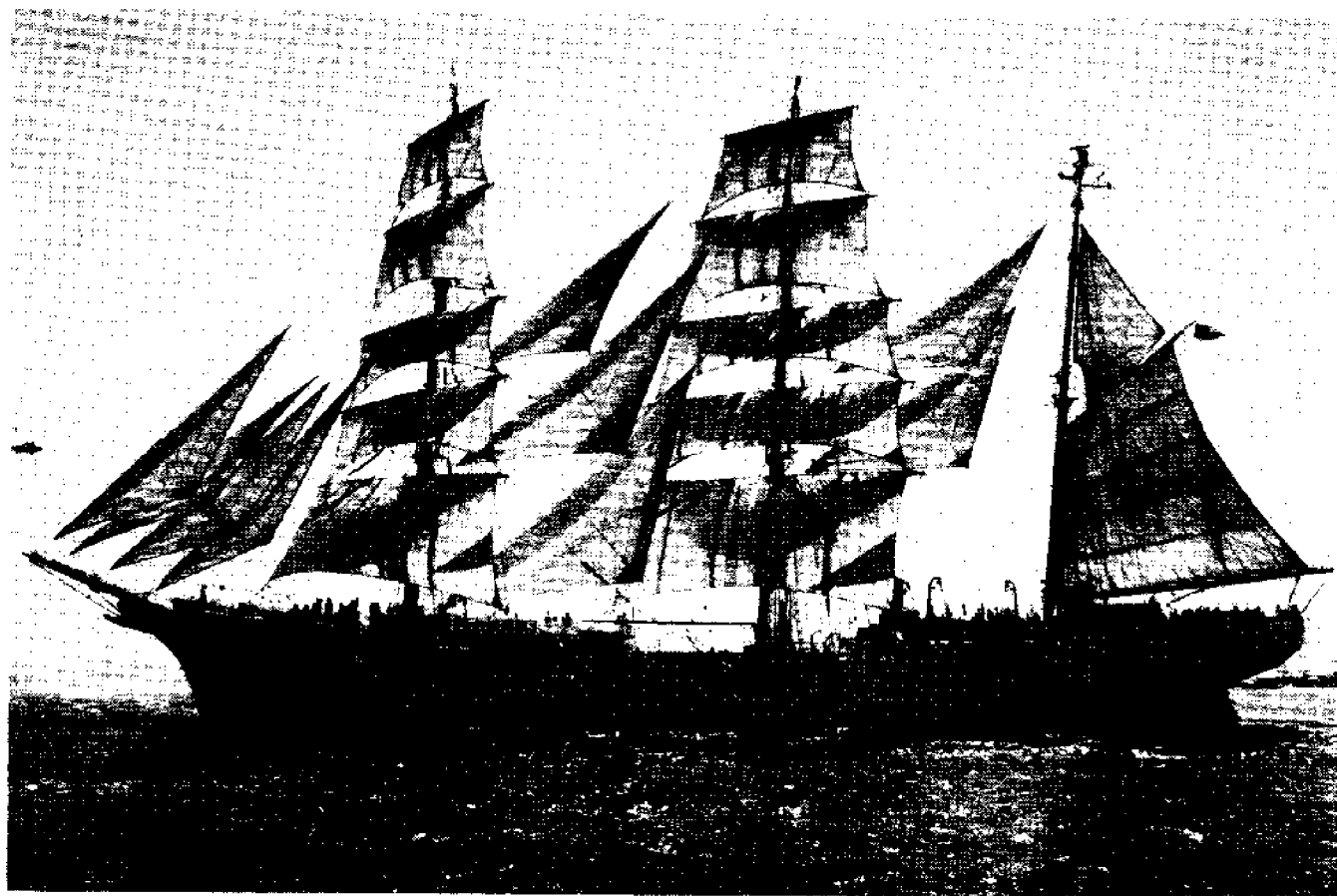


Marine Studies of San Pedro Bay, California

PART 14 BIOLOGICAL INVESTIGATIONS

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Edited by
Dorothy F. Soule and Mikihiro Oguri

Published by
Harbors Environmental Projects
Allan Hancock Foundation

and
The Office of Sea Grant Programs
Institute of Marine and Coastal Studies

University of Southern California
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On the cover: The Coast Guard training vessel EAGLE entering the Port of Long Beach. Photo courtesy of the Port of Long Beach.

MICROBIAL STANDING STOCKS AND METABOLIC
ACTIVITIES OF MICROHETEROTROPHS IN SOUTHERN
CALIFORNIA COASTAL WATERS

by

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ABSTRACT. Bacterial standing stocks at seven stations varied over three orders of magnitude, 10^8 to 10^{11} bacteria \cdot L $^{-1}$. The size of these stocks appeared to be positively correlated with known input of organic matter, decreasing as distance from shore increased.

Turnover times of 1.2h to 25h indicated that various dissolved organic compounds were rapidly metabolized by the natural assemblage of harbor waters under simulated in situ conditions. At stations inside the harbor a potential of 29 to 50 μ g glucose \cdot L $^{-1}$ day $^{-1}$ was metabolized by microheterotrophs. Of the glucose and amino acids metabolized 21% to 37% were respired as CO $_2$; the remaining 63% to 79% was incorporated into microbial biomass and was made available to higher trophic levels through the detrital food web.

Size fractionation of 14 C-algal hydrolysate and 3 H-glucose showed that approximately 91% to 98% of the organic matter incorporated by microheterotrophs passed through 5 μ pore size filters and at least 72% passed through 1 μ pore size filters.

ACKNOWLEDGMENTS. I would like to thank Ms. M. Ninos and Dr. Dale Kiefer for the chlorophyll a determinations, Dr. B.C. Abbott for the use of his epifluorescence microscope, and Mr. Timothy Sharpe for his technical assistance. A special thanks is due Dr. D.F. Soule, Director of the Harbors Environmental Projects, for the cooperation of technicians and generous use of shiptime on the Golden West. This work was supported in part by USC Sea Grant Program Development Project #04-6-158-44118 from NOAA to C.W. Sullivan. Matching funds were provided by the Tuna Research Foundation and City of Los Angeles contracts to D.F. Soule, principal investigator.

INTRODUCTION

The purpose of this report is to present some preliminary findings of studies which were initiated in September 1977 under a program development award from USC Sea Grant (entitled: Distribution and Activity of Microheterotrophs in California Coastal Waters) in cooperation with the Harbors Environmental Projects. I wish to stress the preliminary nature of these findings since the studies cover only a 4-month period, September-December, 1977.

Microheterotrophs are operationally defined here by two criteria; as organisms which:

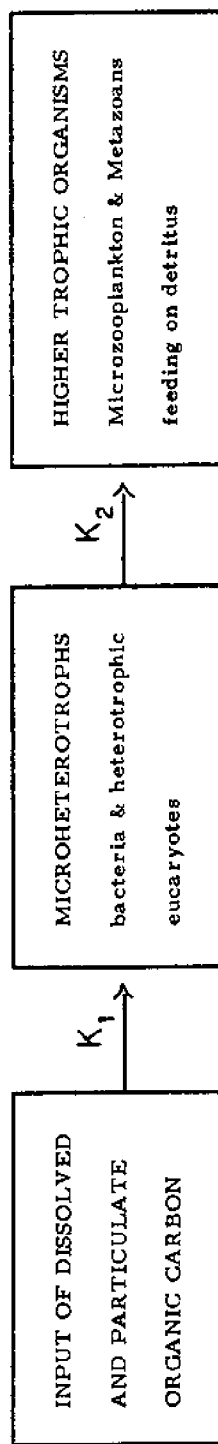
- 1) take up ^3H - and ^{14}C - radiolabeled, dissolved organic compounds (DOC) from sea water.
- 2) pass through a 203 μ nylon mesh net (NITEX) and are retained by a 0.2 μ pore size membrane filter (Nuclepore).

Known organisms which may be included within the grouping are: bacteria, heterotrophic and facultatively heterotrophic microalgae and possibly protozoa such as ciliates and amoebae.

We have come to understand that it is the nature of microbial communities to be poised for active metabolism, growth and reproduction when the physical and chemical environment presents conditions favorable for these biological activities. Among the most notable of these conditions is the availability of readily utilizable reduced organic substrates which serve as sources of carbon and energy for heterotrophic microbial growth. One must appreciate from the outset that the dynamic nature of microbial communities is such that experimental monitoring must be conducted on a regular basis and that these studies must be conducted over a period of at least a year. From such a sampling program we might begin to gain some understanding of the temporal (seasonal, diurnal, tidal, etc.) variability of standing stocks, metabolic activities, and growth rates of the microbial populations which comprise these communities.

The long range objectives of our study group on marine microbial ecology can be stated in a rather simple and straightforward manner; the solutions and answers to the questions asked, however, are considerably more complicated. It is for this reason that we have decided on a multifaceted approach to solve each of the questions which we consider important and integral parts of The Problem: understanding the cycling of organic carbon in coastal waters by marine microheterotrophs.

Figure 1 Schematic of the Detrital Food Web



k_1 = rate of uptake of organic molecules (mg carbon/time)

k_2 = grazing rate of higher trophic organisms on standing stocks of microheterotrophs

METHODS

Sampling

Water samples were taken for microbiological studies at stations within the Los Angeles Harbor, just outside the breakwater, 11 miles offshore in mid-San Pedro Channel, and in Fishermans Cove, Santa Catalina Island (Fig. 2.). For all stations the surface temperatures varied from 17.1° to 21.2°C, bottom temperatures 12.7°C to 17.4°C and the salinities ranged from 32.0‰ to 34.1‰. Samples were collected at a depth 1 meter below the surface and 1 meter above the bottom using a 1.5 L sterile plastic bag (Niskin sampler type, General Oceanics, Fla.) and the samples were processed immediately or placed on ice in a covered ice chest for transport to the laboratory. Samples (500 ml) for quantitative analysis of amino acids according to Adams (1974) were sequentially filtered through 5μ, 1μ and 0.2μ membrane filters (Nucleopore) on board ship. The filtrate was placed in a sterile polycarbonate Erlenmeyer flask and packed in ice for transport to the laboratory.

Size Fractionation

All water samples were passed through a 203μ mesh Nitex net to remove zooplankters. The designation "total values" refers to analysis of material in the 203μ filtrate which is collected on a 0.2μ membrane filter. All membrane filtration studies utilized the 47 mm diameter Nucleopore filters of discrete porosity (Nucleopore Corp., Pleasanton, California) and a vacuum pressure of -10cm Hg.

For size fractionation studies, duplicate aliquots of 1 to 100 ml were filtered through 5μ, 1μ, 0.6μ or 0.2μ membrane filters. The data from such a fractionation is reported as activity retained by a particular pore size or as activity passing a given pore size. In the latter case, the following formula was used; we assume that all biological material is retained by a 0.2μ pore size filter.

$$\% \text{ passing pore size } x = \frac{\text{Activity } 0.2\mu - \text{Activity } x\mu}{\text{Activity } 0.2\mu} \times 100\%$$

ATP Biomass

ATP biomass was estimated according to the method of Holm-Hansen and Booth (1966). For ATP analysis 25 to 75 ml of water was filtered through 0.2μ or 1μ membrane filters (Nucleopore). The retentate was killed by rapidly submerging the filter in 5 mls of boiling Tris-buffer for 5 min, at 100°C. The extracts were frozen at -20°C until analyzed. ATP content of the extract was determined by the luciferin-luciferase reaction using the ATP photometer. ATP values were converted to cellular organic carbon by the relationship, according to Holm-Hansen (1970):

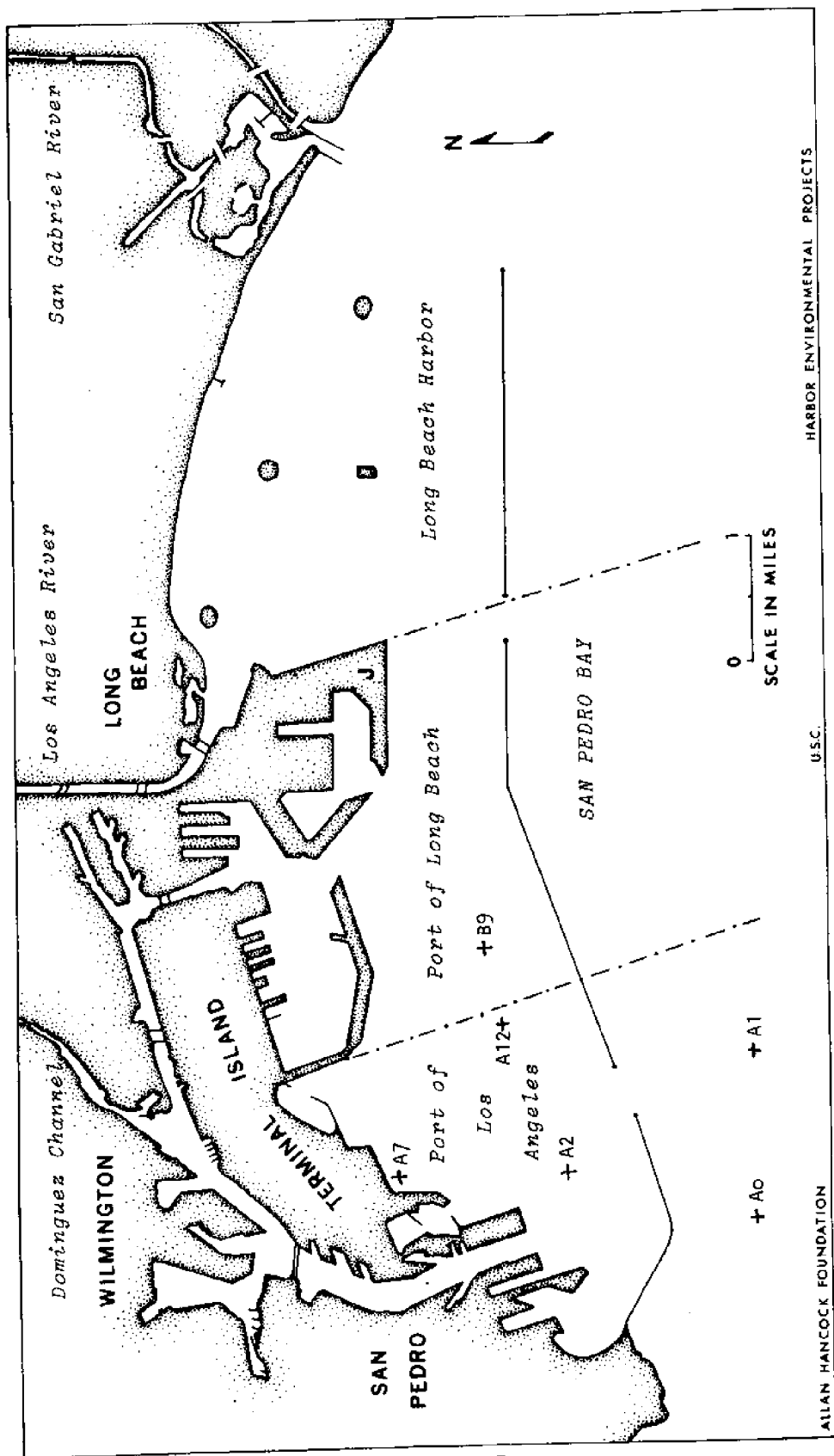


Figure 2. Stations for microbiological sampling in southern California coastal and harbor waters. Not depicted are mid-San Pedro Channel and Santa Catalina Island, Big Fisherman's Cove station.

$$\mu\text{g ATP} \cdot \text{L}^{-1} \times 250 = \mu\text{g Carbon} \cdot \text{L}^{-1}$$

Plate Counts of Bacteria

1.0 ml aliquots of sample were diluted in sterile modified f/2 medium pH 7.6. Duplicate plates were prepared using 0.1 ml of serial dilution, inverted, and incubated at 18°C for 7 days. Colony counts were made on plates containing 30 to 300 colonies. The values given are the average of these counts multiplied by the dilution factor. Plating media are described in the legend of Table 4.

Epifluorescence Microscopy

Direct counting of Acradine Orange stained bacteria retained on 0.2 μ pore size, black, Sartorius membrane filters (24 mm dia.) was carried out according to the method described by Daley and Hobbie (1975). Cells were viewed by use of an inverted Zeiss microscope equipped with epifluorescence illuminator and FITC filter. Only green fluorescing particles of bacterial shape and size with a definite regular boundary were counted. At least 10 fields, each containing 10 to 60 cells, were counted per sample. The numbers of bacteria per sample were calculated using the following formula:

$$\frac{\text{no. bacteria}}{\text{ml water}} = \frac{\text{aver. no. bacteria}}{\text{field}} \times \frac{1.56 \times 10^4 \text{ fields}}{\text{filter}} \times \frac{1}{\text{vol. filtered in ml.}}$$

Phytoplankton Biomass

Duplicate water samples of 25 to 100 ml were filtered on membrane filters as described earlier. The filter containing cells was extracted in 90% acetone (10% H₂O) at 5°C overnight according to Strickland and Parsons (1972). Chlorophyll a fluorescence was determined on the extracted material using an Aminco-Bowman spectrophotofluorometer according to Kiefer (1972). Chlorophyll a values were corrected for interference by phaeopigments. Phytoplankton biomass was estimated by the conversion factor: $\mu\text{g chlorophyll } a \cdot \text{L}^{-1} \times 50 = \mu\text{g phytoplankton carbon} \cdot \text{L}^{-1}$.

Heterotrophic Activity

The heterotrophic activity of the natural microbial assemblage was measured under simulated in situ conditions by the use of ³H- and ¹⁴C- uniformly labeled substrates.

Uptake and Incorporation. Kinetic studies of ³H-labeled substrates were performed by addition of 1 ml of radiolabeled substrate (10 $\mu\text{Ci} \cdot \text{ml}^{-1}$ and specific activity 18 to 50 Ci $\cdot \text{mMole}^{-1}$ respectively for glucose and thymidine) to 99 ml of 203 μ filtered sample water contained in a sterile 250 ml screw-capped Erlenmeyer flask. This

resulted in nanomolar concentrations of labeled substrate in the assay. These concentrations are believed to be below the natural concentrations of glucose and amino acids especially in eutrophic coastal waters (Hobbie, Crawford, Webb, 1968; Riley and Segar, 1970; Clark, Jackson and North, 1972).

Immediately following addition of the label, duplicate 10 ml aliquots were filtered through 0.2 μ filters and washed with 2-10 ml aliquots of ice cold sterile sea water. These samples served as background control and were assumed to represent filter and cell adsorption of labels. The flask was incubated on a rotary shaker at 100 rpm, 18°C, and duplicate 10 ml samples were removed at 30, 60, 90 min and treated as described for the control. The filters were dried for 1 h under an infrared lamp then radioassayed in vials containing 10 ml of scintillation fluid (3.79L toluene: 18.5g PPO: 379 mg POPOP). Radioassay data was corrected by the external standard ratio method; the background control was used to correct all uptake data.

Metabolism. Incorporation and respiration of ^{14}C -labeled substrates was measured using 10 ml of water according to the methods of Hobbie and Crawford (1969). The method is similar to that outlined above except that the assay is carried out in a stoppered serum bottle fitted with a phenethylamine $^{14}\text{CO}_2$ - trap. While this method has the advantage of directly measuring respiration of carbon substrates, a metabolic loss not accounted for by the ^3H -substrate method, it has the possible drawback of requiring the addition of high substrate concentrations (0.1 to 1 $\mu\text{mole} \cdot \text{L}^{-1}$) because of the inherent low specific activity of ^{14}C -labeled compounds. This apparently is not a significant problem in coastal and harbor waters under investigation, since gas chromatographic analysis of amino acids conducted in Dr. W. O. McClure's laboratory by S. Brady indicates that 0.1 to 10 μmolar amino acid concentrations are present in these waters (arginine > cysteine > lysine > tyrosine > histidine > glutamate > isoleucine > ornithine > aspartate > tryptophan > serine).

The substrates were used at final concentrations of 0.1 or 0.01 $\mu\text{Ci/ml}$ and the specific activities of various radio-labeled compounds were as follows: ^{14}C -glucose, 250 $\text{mCi} \cdot \text{mMole}^{-1}$; ^{14}C - algal protein hydrolysate (a mixture of 15 amino acids of varying specific activities, 156 to 460 $\text{mCi} \cdot \text{mMole}^{-1}$).

Turnover Times

The turnover times for various substrates were calculated from velocities of total uptake or metabolism determined by kinetic analysis of the time course of these parameters at 0, 30, 60 and 90 min. Velocities were determined at times when substrate utilization was linear with time and when less than 15% of the total label had been metabolized.

The turnover time (t) of a substrate refers to the time required

for a natural microbial assemblage to completely metabolize the substrate and is calculated as follows:

$$t = s/v$$

where t is the turnover time in hours; s is the total substrate expressed as total disintegrations per min (DPM) per assay; and v is the rate at which the substrate is removed by the microbes expressed as $\text{DPM} \cdot (\text{assay} \cdot \text{h})^{-1}$.

$^{14}\text{CO}_2$ -Fixation

The standard $^{14}\text{CO}_2$ -bicarbonate primary productivity assay described by Strickland and Parsons (1972) was used with the exception that the assay was terminated by filtration through membrane filters as described for heterotrophic uptake. For each 200 ml assay, 5 μCi $\text{NaH}_2^{14}\text{CO}_3$ was added; incubation was at 18°C , 5000 lux for 24 hr. Dark bottle controls were subtracted from light bottle uptake values.

RESULTS AND DISCUSSION

Microbial Biomass

The total microbial biomass in surface waters inside the harbor was consistently highest at station A7 and represented microbial standing stocks of 0.92 to 1.6 mg carbon $\cdot \text{L}^{-1}$ (Table 1). The microbial standing stocks of water outside the harbor were consistently lower than inside the breakwater. There was a consistent 2- to 3-fold higher standing stock in the surface sample compared with the bottom sample at all harbor stations, while station A0, outside the breakwater, showed surface and bottom standing stocks which were not significantly different.

Bacterial Population Densities

Direct counting of Acradine Orange stained bacteria with the epifluorescence microscope (Table 2) essentially reflected in a qualitative fashion the total biomass distribution presented in Table 1.1, as determined by the ATP method. Again A7 surface waters showed the highest bacterial population densities, ranging from about 1 to 10×10^{10} cells $\cdot \text{L}^{-1}$. Surface waters directly outside the harbor have bacterial densities which are one to two orders of magnitude lower, and further offshore, in the San Pedro Channel and near Catalina Island, the bacterial densities are about 250 to 1000 times lower than in the harbor.

Size Fractionation of Microbial Biomass

An attempt was made to fractionate the total microbial assemblage into two size classes on the basis of ATP extracted from 1μ and 0.2μ

TABLE 1. Total Microbial Biomass* in California Coastal and Harbor Waters
Determined by ATP Method

| STATION | SAMPLE DATE | | |
|-------------|---------------|---|----------------|
| | 8/3/77 | 9/14/77 ($\mu\text{g Carbon} \cdot \text{L}^{-1}$) | 10/5/77 |
| Ao surface | N.S. | 46 \pm 4 | 376 \pm 122 |
| bottom | | 50 \pm 7 | 341 \pm 65 |
| A2 surface | 481 \pm 4 | 662 \pm 72 | 706 \pm 101 |
| bottom | 431 \pm 149 | 140 \pm 45 | 164 \pm 48 |
| A7 surface | 915 \pm 40 | 998 \pm 0 | 1682 \pm 474 |
| bottom | 466 \pm 6 | 252 \pm 50 | 538 \pm 196 |
| A12 surface | 448 \pm 38 | 298 \pm 128 | N.S. |
| bottom | 275 \pm 10 | 121 \pm 16 | |
| B9 surface | 853 \pm 56 | 278 \pm 30 | N.S. |
| bottom | 319 \pm 21 | 168 \pm 40 | |

*Material in 203 μ filtrate which is retained by a 0.2 μ filter.

⁺N.S. - not sampled.

TABLE 2. Bacterial Population Densities in California Coastal and Harbor Waters Determined by Direct Epifluorescent Microscopic Counting

| STATION | SAMPLE DATE | | | |
|--|---------------|--|--------------|---------------|
| | 9/15/77 | 10/5/77 (10^8 bacteria \cdot L $^{-1}$) | 11/2/77 | 12/13/77 |
| Ao surface | 6.2 \pm 1.3 | 9.7 \pm 1.4 | 20 \pm 5.1 | 64 \pm 9.9 |
| bottom | 2.8 \pm 1.8 | 9.2 \pm 1.4 | | |
| A2 surface | 23 \pm 5.7 | 99 \pm 11 | 197 \pm 47 | 482 \pm 67 |
| bottom | 13 \pm 3.2 | 44 \pm 4 | | |
| A7 surface | 170 \pm 44 | 227 \pm 21 | 505 \pm 95 | 998 \pm 195 |
| bottom | 54 \pm 9.8 | 152 \pm 23 | | |
| A12 surface | 11 \pm 4.7 | N.S. | N.S. | N.S. |
| bottom | 15 \pm 2.4 | | | |
| B9 surface | 43 \pm 8.1 | N.S. | N.S. | N.S. |
| bottom | 27 \pm 11 | | | |
| | | | | |
| | | 10/76 | 10/77 | |
| Fishermans Cove (Catalina Island) surface | | N.S. | 3.9 | |
| 20 m | | | 4.3 | |
| San Pedro Channel surface | | 1.2 | N.S. | |

N.S. - not sampled

filtered water samples: one $< 203\mu > 1\mu$, and a second $< 1\mu$ and $> 0.2\mu$. The results shown in Table 3 indicate that the biomass fraction $< 1\mu > 0.2\mu$ varies from 19% to 80% of the total. Unfortunately this fraction does not correlate with the bacterial biomass as well as was expected, although several other lines of evidence suggest that it is dominated by bacteria. It should also be noted that the sum of bacterial biomass and phytoplankton biomass account for only 30% to 83% of the total biomass as determined by the ATP method. These values are less consistent than expected and may reflect problems with the biomass conversion factors chosen or some of the assumptions made in calculating these factors. It is at least gratifying that these estimates agree within a factor of 3 of each other. We are planning more thorough studies of direct cell counting of phytoplankters, using the inverted phase-contrast microscope and SEM techniques, to improve the accuracy and reliability of our biomass estimates. Alternatively, differences in biomass estimates may have resulted from variable populations of achlorophyllous microalgae and various eucaryotic Protista, generally grouped as microzooplankton. A number of ciliates, amoebae and small flagellated cells have been observed by phase contrast microscopy in fresh samples.

Since many standard methods and procedures often rely on conventional spread plate techniques for bacterial counts, we decided to compare our estimates of bacterial population densities by the direct counting technique using the epifluorescence microscope versus spread plating on marine agar plates of varying nutrient characteristics. Our findings suggest that plate counting techniques can lead to serious underestimates of standing stocks of bacteria, as reported earlier by others (Jannasch, 1967; Hoppe, 1976). The results in Table 4 revealed that the plating efficiency of marine bacteria varied between 0.8% and 10%. Thus only 1 to 10 of every 100 marine bacteria grew on agar media under our conditions of incubation. It is important to note that the water samples were never subjected to temperatures greater than 18°C . Therefore the organisms were not thermally stressed.

Although the data are limited, it appears that the bacterial assemblage at station A7, which received highest organic inputs from the cannery effluent, had the highest plating efficiency. Interestingly, bacteria from this station were large and appear to have morphologies typical of laboratory cultures, i.e. rod-shaped bacteria in exponential growth phase. Also, the bacteria from A7 were often seen by fluorescence microscopy in long chains of 10 to 20 cells.

A thorough study by standard plate counts (SPC) of aerobic heterotrophic microorganisms and of fecal coliforms was conducted by Juge and Griest (1975) in the Los Angeles-Long Beach Harbor waters. It was found that series "A" stations (except A1) had standing stocks of bacteria of $10^{4.5}$ to $10^{5.8} \cdot \text{ml}^{-1}$ by SPC and $10^{4.5}$ for total coliforms. In both assays, station A7 was consistently the highest; our data are in good agreement on this observation.

TABLE 3. Size Fractionation of Microbial Biomass from California Coastal and Harbor Waters on 10/5/77.

| STATION | Size fraction (μ) | ATP-biomass $\mu\text{gC}\cdot\text{L}^{-1}$ (fraction as % of total <1 μ) | Bacterial biomass $\mu\text{gC}\cdot\text{L}^{-1}$ (% of total ATP) | Phytoplankton biomass $\mu\text{gC}\cdot\text{L}^{-1}$ (% total ATP) |
|------------|----------------------------|--|---|--|
| Ao surface | 1.0 | 76.3 \pm 8.3 | | |
| | 0.2 | 376 \pm 121 (80%) | 17.4 \pm 2.5 (4.6%) | 94.5 (25%) |
| bottom | 1.0 | 276 \pm 22 | | |
| | 0.2 | 341 \pm 65 (19%) | 16.5 \pm 2.6 (4.8%) | N.S. |
| A2 surface | 1.0 | 407 \pm 56 | | |
| | 0.2 | 706 \pm 101 (42%) | 178 \pm 20 (25.3%) | 411 (58%) |
| bottom | 1.0 | 131 \pm 5 | | |
| | 0.2 | 163 \pm 47 (20%) | 78.6 \pm 7.3 (48%) | N.S. |
| A7 surface | 1.0 | 812 \pm 183 | | |
| | 0.2 | 1682 \pm 474 (52%) | 406 \pm 38 (24%) | 252 (15%) |
| bottom | 1.0 | 268 \pm 94 | | |
| | 0.2 | 528 \pm 196 (49%) | 273 \pm 42 (52%) | N.S. |

Biomass calculations were made as follows:

- Total ATP-biomass = $\mu\text{gATP/L} \times 250 = \mu\text{g carbon/L}$.
- Phytoplankton biomass = Chlorophyll a/L $\times 50 = \mu\text{g Carbon L}$.
- Bacterial biomass = assume spherical cells of diameter 0.6 μ and 40% dry wt as carbon (1.8×10^{-5} ng/bacterium \times #bacteria) = $\mu\text{g Carbon/L}$.

TABLE 4. Bacterial Population Estimates Determined by Direct Epifluorescent Microscopy vs Plate Counting on 10/5/77.

| STATION | DIRECT COUNT (bacteria $\times 10^8 \cdot L^{-1}$) | SPREAD | PLATE | MEDIUM |
|------------|--|-----------------|---------------|----------------|
| | | 2216 | SWNA | f/2 |
| Ao surface | 9.7 ± 1.4 | 0.41 (4.2%) | 0.11 | 0.01 |
| bottom | 9.2 ± 1.4 | 0.07 (0.76%) | 0.006 | 0.01 |
| A2 surface | 99.8 ± 11 | 6.8 (6.8%) | 2.0 | 3.4 |
| bottom | 43.9 ± 4.1 | 0.16 | 0.15 | 4 (9.1%) |
| A7 surface | 227 ± 21 | 4.5 | 6.5 | 12.4 (5.4%) |
| bottom | 152 ± 23 | 17.2 (11%) | 7.7 (5.0%) | 17.3 (11%) |

Media are all prepared using 0.22 μ filtered sea water or are made isotonic with sea water and contain 1.5% agar.

Incubation of plates was at 18°C for 7 days.

2216 = Bacto Marine Agar 2216, Difco Lab.

SWNA = Bacto Nutrient Agar prepared with sea water.

f/2 = Sea water based phytoplankton medium, no organics added.

A most interesting observation also made by Juge and Griest (1975) was that all but one of 17 bacteria isolated from the L.A. Harbor was found to have extracellular enzymes against at least one of the following substrates: gelatin, starch, casein, & tween 80. We might predict such a requirement for organisms which reside on and utilize solid substrates or which attack soluble macromolecules as sources of carbon and energy. This observation requires further investigation into the role these bacteria might play in the cycling of particulate organic carbon in marine waters.

Kinetics of Uptake and Metabolism of Dissolved Organic Substrates by Microheterotrophs

The time course of ^{14}C -labeled amino acid metabolism by the natural microbial community of bottom water at station A7 is shown in Fig. 3a. It can be seen that amino acids were rapidly taken up and metabolized. As much as 33% of the radiolabel taken up by the organisms was respired as $^{14}\text{CO}_2$; the remainder was incorporated into particulate biomass greater than 0.2μ in diameter. ^{14}C -glucose uptake and metabolism by microheterotrophs from surface water at station A7 was likewise quite rapid and proceeded in a linear fashion during the incubation period. At the observed rate, at least $42\text{ }\mu\text{g glucose} \cdot \text{L}^{-1} \cdot \text{day}^{-1}$ was utilized at station A7 surface waters (Fig. 3b). At various time points glucose respiration was 22% to 27% to total uptake. When ^3H -glucose was added to surface waters of station A2 (Fig. 3c), we found a rapid uptake and conversion into particles 1μ . Substrate limitation apparently caused a leveling of uptake during the 1.5 h incubation period; in such active amples only 30 min data was used to calculate kinetic characteristics. Similar results were found for ^3H -thymidine at station A7 surface water on 9/23/77 (Fig. 3d).

Size Fractionation of Heterotrophic Activity and Substrate Turnover Time

A major component of the organic fraction of cannery effluent is fish protein, peptides and dissolved amino acids. Previous studies have indicated high levels of dissolved amino acids in the cannery effluent (Chamberlain, 1975). Therefore, it was of considerable importance to determine the fate of these organic molecules in the receiving waters of the harbor and contiguous coastal waters. For test substrate, we chose a commercially available mixture of 15 ^{14}C -labeled amino acids derived from algal protein hydrolysate. The results of this experiment depicted in Table 5 are most informative.

The relative heterotrophic uptake ($\text{DPM} \cdot 10\text{ ml}^{-1} \cdot \text{h}^{-1}$) for harbor stations A2 and A7 is greater in bottom water compared to surface water. This seems surprising at first, considering the 2- to 3-fold greater total microbial biomass and bacterial density in the surface water as seen in Tables 1 and 2. A possible explanation is that the harbor water is stratified with respect to organic concentration, resulting

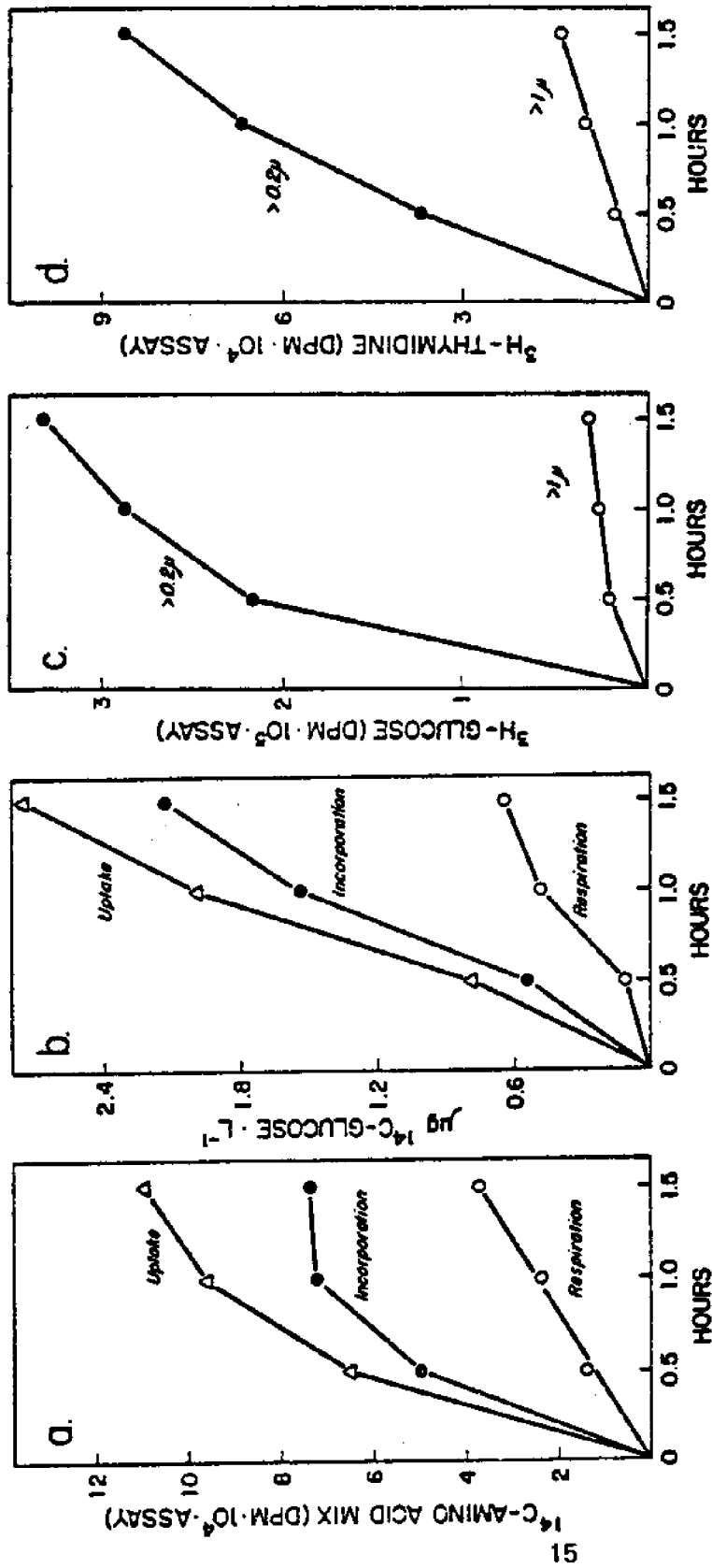


Figure 3. Kinetics of uptake and metabolism of dissolved organic substrates by microheterotrophs from harbor waters.

- Station A7 bottom water, 10/5/77: Δ, total uptake; ●, incorporation; ○, respiration of ^{14}C -amino acids from algal protein hydrolysate ($0.1 \mu\text{Ci/ml}$).
- Station A7 surface water, 9/22/77: Δ, total uptake; ●, incorporation; ○, respiration of ^{14}C -glucose added at a final concentration of $2.6 \times 10^{-9}\text{M} \cdot \text{L}^{-1}$ ($0.01 \mu\text{Ci/ml}$).
- Station A2 surface water, 9/22/77: ●, incorporation into particles $>0.2 \mu$; ○, incorporation into particles $>1 \mu$. Substrate was ^3H -glucose added at a final concentration of $5.5 \times 10^{-9}\text{M} \cdot \text{L}^{-1}$ ($0.1 \mu\text{Ci/ml}$).
- Station A7 surface water, 9/22/77: ●, incorporation into particles $>0.2 \mu$; ○, incorporation into particles $>1 \mu$. Substrate was ^3H -thymidine added at a final concentration of $8 \times 10^{-10}\text{M} \cdot \text{L}^{-1}$ ($0.1 \mu\text{Ci/ml}$).

TABLE 5. Size Fractionation of ^{14}C -algal Protein Hydrolysate Incorporated by a Natural Assemblage of Microheterotrophs from California Coastal and Harbor Waters.

| STATION | SIZE FRACTION (pore size, μ) | ^{14}C Amino Acids Retained (DPM/10 ml/h) | Percent Passing Filter* | Turnover Time s/v(h) |
|------------|--------------------------------------|--|----------------------------|----------------------------|
| Ao surface | 5.0 | 544 | 97.9 | 458 |
| | 1.0 | 1957 | 92.3 | 127 |
| | 0.6 | 13901 | 45.1 | 17.9 |
| | 0.2 | 25310 | - | 9.8 |
| bottom | 5.0 | 566 | 95.9 | 440 |
| | 1.0 | 549 | 94.1 | 454 |
| | 0.6 | 3424 | 63.1 | 72.8 |
| | 0.2 | 9262 | - | 26.9 |
| A2 surface | 5.0 | 2306 | 90.4 | 108 |
| | 1.0 | 3868 | 84.4 | 64.4 |
| | 0.6 | 3453 | 86.1 | 72.2 |
| | 0.2 | 24687 | - | 10.1 |
| bottom | 5.0 | 976 | 98.7 | 255 |
| | 1.0 | 5441 | 92.7 | 45.8 |
| | 0.6 | 41247 | 44.7 | 6.0 |
| | 0.2 | 74181 | - | 3.4 |
| A7 surface | 5.0 | 4021 | 91.1 | 61.9 |
| | 1.0 | 12520 | 72.2 | 19.9 |
| | 0.6 | 28335 | 36.9 | 8.8 |
| | 0.2 | 44885 | - | 5.5 |
| bottom | 5.0 | 2194 | 97.2 | 113 |
| | 1.0 | 8842 | 87.4 | 29.6 |
| | 0.6 | 30341 | 60.3 | 8.2 |
| | 0.2 | 76305 | - | 3.3 |

Sample date 10/5/77

$$*\% \text{ passing filter} = \frac{\text{DPM}_{0.2\mu} - \text{DPM}_{x\mu}}{\text{DPM}_{0.2\mu}} \times 100\%$$

from surface input of effluents in low density water. This effect would result in natural amino acid concentrations being higher in surface waters. This would have the effect of diluting the radioisotope added to the surface sample, lowering its in situ specific activity; it would thus lower the apparent incorporation rate ($\text{DPM} \cdot \text{h}^{-1}$) while the absolute rate would be higher ($\mu\text{moles amino acid} \cdot \text{h}^{-1}$). This hypothesis will be tested in future experiments in which the amino acid concentration will be estimated by gas chromatographic analysis so that absolute incorporation rates can be determined.

Which size fraction of the microbial assemblage incorporates the amino acids? A remarkably consistent pattern emerged from the size versus heterotrophic activity profile for incorporation at all stations. Most notable is the fact that 72% to 94% of the incorporated amino acids passed through 1μ pore size Nuclepore filters. Such a finding is surprising for nearshore coastal waters and highly eutrophic waters of the harbor, which are rich in particulate material (Secchi depths of 0.5m to 11m) which might be expected to provide surfaces for microbial attachment as reported by Jannasch (1967), Seki (1972), and Pearl (1975) in oceanic and coastal waters.

Rather, the size fraction vs. heterotrophic activity seen here bears greater similarity to that reported for southern California Bight waters 100 km from shore, by Azam and Hodson (1977). In their studies, 90% of the heterotrophic activity was filterable through 1.0μ Nuclepore filters. Hoppe (1976) in Kiel, Germany found 70% and 45% of the heterotrophic activity in the 0.4μ - 0.6μ size fraction of polluted Kiel Bay and Kiel Bight (offshore), respectively. These latter two studies indicate that most of the organisms heterotrophically active on ^3H - and ^{14}C -labeled substrates are free in the water column and are not associated with particulates greater than 0.6μ to 1.0μ in their lesser diameter. See Azam and Hodson (1977) for some critical comments of the assumptions inherent in this interpretation of the data.

The turnover times of the organic substrates tested in these studies were among the highest reported in the current literature (Azam and Holm-Hansen, 1973; Crawford, Hobbie, Webb, 1974; Sibert and Brown, 1975). All substrates at all Los Angeles Harbor stations tested had turnover times of less than 25h. Turnover times at stations outside the harbor were consistently higher and ranged from 15h to 1200h. Amino acids in coastal and harbor waters appear to be metabolized quite rapidly; turnover times ranging from 1.1h to 1.3h at A7; 1.7h to 25h at A2, and 15h to 94h at A0 were found. Turnover times for ^3H -glucose at the stations sampled were also quite rapid; 2.8h to 5.2h at A7 surface, 7h to 12h at A7 bottom, and 3.9h at A2 surface. Clearly turnover time decreases as one moves towards the eutrophic waters of the inner harbor.

An interesting comparison of the relative importance to carbon cycling of organisms in the size range 203μ to 5μ versus 1μ to 2.0μ

can be made by examining the turnover times of the algal protein hydrolysate by these two groups (last column, Table 5). The first, 203 μ - 5 μ , is responsible for amino acid turnover times of 62h to 458h, while the latter, 1 μ - 0.2 μ , shows turnover times of 3.4h to 72h. A possible interpretation of this data is that the smaller size fraction is as much as 75 times more metabolically active on dissolved amino acid substrates than the larger fraction.

We have conducted similar studies using different organic substrates which gave results very similar to those reported for amino acid mixtures. When ^3H -glucose was added to surface water samples from station A2 to a final concentration of 5.5 nanomoles $\cdot \text{L}^{-1}$ ($5.5 \times 10^{-9}\text{M}$) the percentage of incorporated material passing various pore-sized filters was as follows: 5 μ , 98.2%; 1 μ , 88%; 0.6 μ , 67%; 0.2 μ , 0%. At station A7, the relationships were: 5 μ , 92.9%; 1 μ , 77%; 0.6 μ , 48%; and 0.2 μ , 0%. When ^3H -thymidine was added to a surface water sample of B9 at a final concentration of 9 0.2 μ , 0%. Very similar results were found at the other stations tested.

Clearly, an understanding of which microbial groups are heterotrophically most active depends on characterizing the size fraction less than 1 μ and greater than 0.2 μ . Some preliminary attempts to accomplish this are shown in Tables 6 and 7. In the first experiment (10/5/77) 0% to 3% of the $^{14}\text{CO}_2$ fixed in the standard primary productivity assay passed the 1 μ filter. Chlorophyll *a* fluorescence appears to be a less reliable tracer of intact phytoplankters, since its size fractionation profile consistently showed greater passage of the filters. This is not surprising since chloroplast fragments and portions of grazed cells or fecal pellets containing chlorophyll *a* might be expected to be quite prevalent in such productive waters.

Table 7 shows how the size versus activity profiles for chlorophyll *a* and $^{14}\text{CO}_2$ -fixed differ from that of heterotrophic activity. There is a clear break in the pattern at the level of 5 μ pore size and this break is even more accentuated at the 1 μ pore size where 72% to 92% of the heterotrophic activity passes while only 0%-18% of the phytoplankton indicators pass.

CONCLUSIONS AND COMMENT

Size fractionation of all reduced organic substrates, including nucleotides, sugars and amino acids, incorporated by the natural assemblage of microheterotrophs revealed that for all stations the most active fractions were always less than 1 μ and were often less than 0.6 μ in their lesser diameter. Size fractionation of ^{14}C -algal protein hydrolysate incorporated by natural assemblages of microheterotrophs showed that at least 91% of the incorporated material passed through 5 μ pore size membrane filters and approximately 50% passed 0.6 μ filters.

The suggests two important conclusions:

- a) Microheterotrophs active on dissolved organic compounds are not predominately associated with large ($>5\mu$) detrital particles.
- b) The dominant organisms which metabolize most of the dissolved organic matter (sugars, amino acids, nucleotides) in the study area are small (less than 1μ in their lesser diameter).

Studies using phase contrast microscopy, the scanning electron microscope (SEM) and culture techniques are currently underway to determine the nature of cells in the size fraction $< 1\mu$ and $> 0.2\mu$ which are responsible for the metabolism of these organic compounds.

TABLE 6. Size Fractionation of $^{14}\text{CO}_2$ Incorporated by a Natural Assemblage of Photoautotrophs in California Coastal and Harbor Waters.

| STATION | SIZE FRACTION | $^{14}\text{CO}_2$ Retained | Percent Fixed Passing | $^{14}\text{CO}_2$ |
|---------------------------|---------------------|-----------------------------|--------------------------|--------------------|
| I. Sample date 10/5/77 | (pore size, μ) | (DPM/100 ml/24 h) | Filter | |
| A0 surface | 5.0 | N.S. | - | |
| | 1.0 | | - | |
| | 0.6 | | - | |
| | 0.2 | | - | |
| A2 surface | 5.0 | 25,144 | 23 | |
| | 1.0 | 31,529 | 3 | |
| | 0.6 | 32,512 | 1 | |
| | 0.2 | 32,670 | - | |
| A7 surface | 5.0 | 8,858 | 10 | |
| | 1.0 | 11,338 | 0 | |
| | 0.6 | 9,538 | 3 | |
| | 0.2 | 9,830 | - | |

| | | | | | | |
|-------------------------|--|-----------------|--|-----------------|--|-----------------|
| II. Sample date 11/2/77 | | | STATIONS | | | |
| PORE SIZE (μ) | Ao | | A2 | | A7 | |
| | <u>¹⁴CO₂ fixed</u> | <u>Chloro a</u> | <u>¹⁴CO₂ fixed</u> | <u>Chloro a</u> | <u>¹⁴CO₂ fixed</u> | <u>Chloro a</u> |
| | (% Passing Filter) | | | | | |
| 5 | 47 | 43 | 28 | 41 | - | 11 |
| 1 | 19 | 31 | 5 | 11 | 28 | 6 |
| 0.6 | 5.2 | 25 | 0 | 5 | 17 | 8 |
| 0.2 | - | - | - | - | - | - |

TABLE 7. Percent of Activity Passing Various Pore Size Filters.

| PORE SIZE (μ) | STATIONS | | | | | | | | |
|------------------------|-----------------------|---|------------------------|-----------------------|-----|------------------------|-----------------------|-----|------------------------|
| | A0 | | | A2 | | | A7 | | |
| | $^{14}\text{CO}_2$ | | ^{14}C -amino | $^{14}\text{CO}_2$ | | ^{14}C -amino | $^{14}\text{CO}_2$ | | ^{14}C -amino |
| | Chloro <u>a</u> fixed | | acid | Chloro <u>a</u> fixed | | acid | Chloro <u>a</u> fixed | | acid |
| 203 | 100 | - | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 5 | 35 | - | 98 | 35 | 33 | 95 | 36 | 10 | 90 |
| 1 | 17 | - | 92 | 18 | 3 | 84 | 0 | 0 | 72 |
| 0.6 | 8 | - | 45 | 14 | 1 | 85 | 0 | 3 | 37 |
| 0.2 | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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DYNAMIC OXYGEN MODEL
OF LOS ANGELES HARBOR RECEIVING WATERS

by

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ABSTRACT

A computer simulation model was developed for the oxygen dynamics in the waters off Terminal Island east of Fish Harbor. Prior to 1978 these waters received heavy organic loading from two outfalls of the fish canneries as well as the primary treated sewage of the Terminal Island Treatment Plant. In formulating this quantitative oxygen budget the study area was divided into three vertically averaged elements, and equations were developed to describe the effect on the level of dissolved oxygen of the following processes: 1) turbulent mixing and advective exchange; 2) air-water exchange; 3) oxidation of BOD (Biochemical Oxygen Demand); 4) oxygen production and uptake by phytoplankton; and 5) oxygen uptake by the bottom sediments. Using values for input variables that were characteristic of harbor waters, model results were consistent with actual field observations for both dissolved oxygen and BOD. Results of sensitivity analyses confirmed the overwhelming importance to the oxygen budget of organic loading and its subsequent oxidation.

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INTRODUCTION

One of the traditional roles of Los Angeles Harbor has been as the receiving waters for effluents. Prior to January 1978 the fish canneries together with the Terminal Island Treatment Plant were particularly important sources that discharged into the waters off Terminal Island east of Fish Harbor. This region of the harbor has been the focus for the current oxygen modeling effort (Fig. 1).

Even though the BOD (Biochemical Oxygen Demand) of the cannery effluent was generally about 1000 mg O₂/l, under typical conditions the BOD of the water was reduced to less than 10 mg O₂/l within 800 m of the outfalls (monitoring data of Tuna Research Foundation on file with Los Angeles Regional Water Quality Control Board). Within about 1200 meters of the discharge site, the BOD level was normally about the same as the rest of the outer harbor. Although water circulation and turbulent mixing contributed to this dramatic decline in BOD, these physical processes were not the only ones involved. The BOD level was also decreased by the chemical oxidation of the effluent and the utilization of the organic wastes by microorganisms. Both these processes require oxygen so, upon occasion, the levels of oxygen in waters in Los Angeles Harbor near cannery discharges became quite low. Because oxygen is essential to most forms of life, low oxygen conditions result in lethal or sublethal environments. Anoxic waters may smell of sulfide or have high counts of anaerobic bacteria, and chronically anoxic waters will not support macrofauna, in violation of water quality standards. It was our goal, therefore, to formulate this simulation model of the oxygen dynamics and to understand the oxygen budget of the receiving waters well enough to avoid low oxygen conditions.

Because the cannery effluent with its high BOD has been an important part of the oxygen dynamics, learning to manage such effluents properly is important. This does not mean, a priori, that it is necessarily the most intelligent course of action to forbid all such discharges. Unlike many industrial wastes, fish cannery wastes are completely "biodegradable." The principal problem locally seemed to be one of occasional low oxygen episodes. If that could have been overcome, then managed discharge may have been possible without long-term adverse effects.

In order to be able to manage the effluent in a sensible way, it was necessary first to understand and quantify with some confidence the processes that were important in governing the oxygen concentration in this area of Los Angeles Harbor. In this study five factors were considered: 1) turbulent mixing and advective exchange by currents; 2) air-water exchange; 3) oxidation of BOD; 4) oxygen production and uptake by phytoplankton; and 5) oxygen uptake by the bottom sediments (Fig. 2).

To facilitate the synthesis and analyses of the relative roles of these processes, a computer simulation model was developed. The creation of such a model required that the important rates be described using

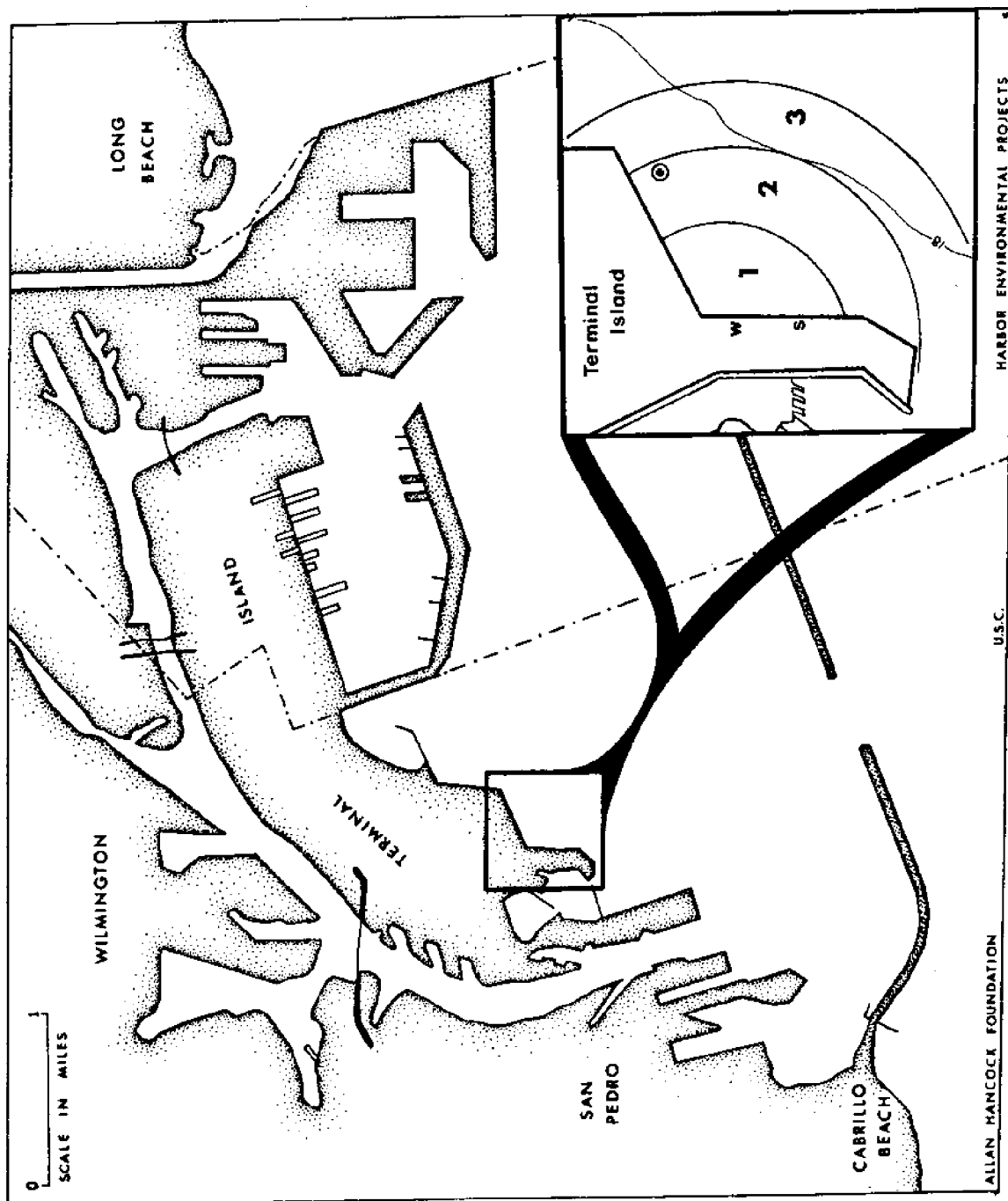


Figure 1. Map of Los Angeles Harbor with detail of three spatial elements included in the oxygen model. "W" and "S" indicate the former positions of cannery effluent discharges while x marks the sewer boil from the Terminal Island Treatment Plant.

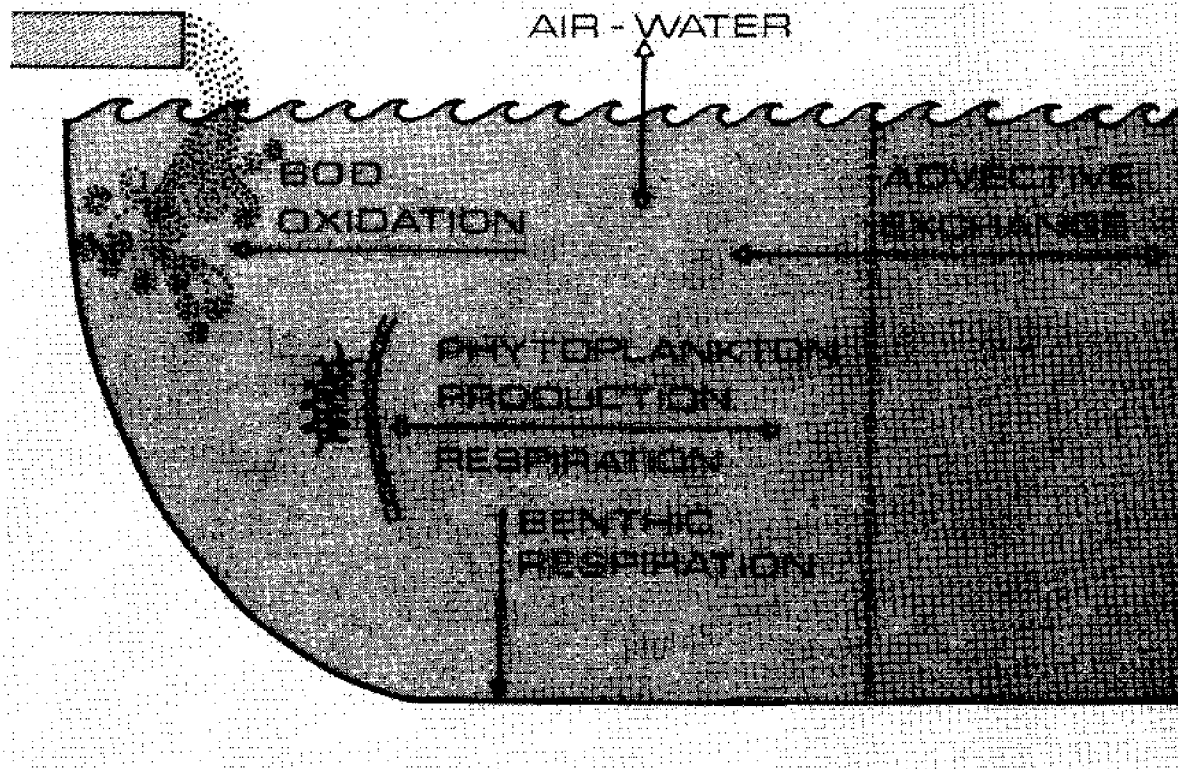


Figure 2. Schematic representation of the five major processes included in the oxygen budget for each spatial element.

The cycling of organic matter in coastal marine ecosystems depends on a balance between input and sinks: metabolic utilization and geochemical immobilization in the sediments. The metabolizable organic substrates are from two major sources: primary production and from the activities of man, such as: sewage effluent, cannery waste, and terrestrial agricultural runoff via rivers and streams. This organic matter can be considered to "drive" one of the major aquatic food webs, the microheterotroph-based detrital food web. Thus if the addition of dissolved and particulate organic nutrients results in bio-enhancement of receiving waters, as proposed by Soule and Oguri (1976), then these organic compounds must enter marine food webs so that organisms at higher trophic levels can use them as sources of carbon and energy. Therefore, we have asked the question: Is a detrital food web operative in the waters under investigation? To answer this question it is incumbent upon us to demonstrate and quantitate the putative coupling of dissolved and particulate organic compounds to higher trophic organisms through the catalytic (metabolic) activities and growth of microheterotrophs. See diagrammatic Fig. 1.

Objectives

Our long range objectives are to make quantitative estimates of the amount and nature of organic material which enters the detrital food web and to determine the rate at which it passes through the first two steps of that web. These two steps result in the conversion of dissolved organic matter through microheterotrophs to higher trophic levels. To attain these objectives we have decided to investigate various methods and approaches which will allow the determination of four critical biological parameters.

- 1) The standing stocks of coastal bacteria.
- 2) The metabolic activities of microheterotrophs.
- 3) The in situ growth rates of marine bacteria.
- 4) The rate of utilization of microbial biomass by organisms at higher trophic levels under simulated in situ conditions.

In this report, we have only begun to answer some aspects of the first two points noted above.

mathematical equations, showing the relationships between the processes and important external driving functions. The resulting computerized oxygen model represents the combination of the various equations using the factors that have been assumed to be important. Its overall validity is only as good as the component formulations that are used in it. For that reason it was necessary to be careful in designing the model and tailoring it to specific questions and problems. The purpose of this model was to quantify the capacity of receiving waters to oxidize the BOD of discharges without producing dangerously low oxygen levels. The model formulations were designed to be flexible and generalized enough to be applied to similar situations in other receiving waters, with appropriate changes in specific coefficients based on the particular characteristics of those systems.

It is not an unreasonable goal to maintain water quality through an effluent management strategy that is compatible with industrial constraints, but the achievement of this goal using a management model is far from routine. Rigorous environmental monitoring must be an intrinsic part of this process, in order to give proper feedback to the model. Presently it does not appear that it will be possible to proceed with this feedback process and further refinement of this particular model in Los Angeles Harbor. Enforcement of NPDES regulations, as interpreted by EPA, have forced the Los Angeles canneries to connect with the Terminal Island Treatment Plant in January 1978. With the cannery effluent going through the Terminal Island Treatment Plant, the nature of the discharge is changed from containing high BOD and high organics to a discharge high in inorganic nutrients. This fundamental difference would need to be reflected in the basic formulation of a model. The model as it is described in this manuscript applies only to the high BOD discharge of the canneries and is not intended to be applicable to the case of secondary treatment.

DESCRIPTION OF THE MODEL

In order to get realistic results this model was tailored to include formulations based on empirical data for the processes that are important in the oxygen budget. The following sections include detailed descriptions of the model and the formulations for the important relationships.

The Physical Framework

The model has not attempted to portray the harbor as a whole, but has concentrated on the smaller region around the cannery discharges, consisting of about 0.64 sq km. This region defined the area of direct impact by the cannery effluent, but not the area of bioenhancement defined by Soule and Oguri, 1976b. In order to make the oxygen model more realistic and therefore more useful, it was desirable to include spatial heterogeneity. This represents a major refinement from the preliminary model effort (Stanley-Miller, et al., 1976). The area

receiving the cannery discharge was parcelled into three vertically averaged concentric elements (Fig. 1), providing a simplified mixing scheme, since each element can exchange only with water from adjacent elements. Although the assumption of vertical homogeneity has clear limitations (Soule and Oguri, 1974, 1976a), the simple concentric spatial framework seems justifiable for this particular shallow region of the harbor.

The radii and sizes of the spatial elements (Table 1) were chosen to be functional in the model and are not based on any hydrographical features. A roughly similar pattern has been demonstrated by survival contours for incubated anchovy eggs and larvae (Brewer, 1976). The volume of the elements is smaller near the discharges, as the radii shorten and the depths become shallower. This provides greater spatial resolution near the effluent sources. The width of each element was kept sufficiently large so that the assumption of exchange only between adjacent elements was valid for time steps of less than an hour.

Time Frame of the Model

Our goal was to examine the immediate and short-term consequences for a given set of conditions. Consequently, the model calculates the oxygen and BOD levels resulting if constant values of temperature, salinity, BOD loading, and phytoplankton biomass persist until a steady state is reached. Phytoplankton production and wind speed vary through the day, but not over a longer period of time in the model. Combined with data gathered from a regular monitoring program, the short-term prognoses of the model were designed to be continually updated, allowing episodes of potentially low oxygen to be anticipated and avoided.

Table 1. Physical Description

| Element | Distance to outer perimeter, meters | Average depth, m | Volume, m ³ | TRF*stations |
|---------|--|---------------------|---------------------------|----------------------------|
| 1 | 300 | 3.8 | 3.42×10^5 | 1A,2A,3A,4A 1B,2B,3B,3C |
| 2 | 540 | 4.7 | 9.53×10^5 | 1C,2C,4B,4C |
| 3 | 795 | 5.7 | 1.93×10^6 | 1D,2D,3D,4D |

* For map of TRF (Tuna Research Foundation) stations see Figure A.2 in Appendix A.

Element 2 to 3 and from Element 3 to 2 and to the water surrounding the modeled area. The results of these calculations are given in Table 2. In the absence of better information, these exchange coefficients represent first approximations of average circulation conditions for this region of the harbor. These coefficients were used in the model to represent the mixing of water between elements containing different concentrations of oxygen and BOD.

Table 2. Initial Estimates of Fractional Exchange for Each Element Based on Results of Dye Study

| <u>E l e m e n t #</u> | | <u>Fraction of Total</u> |
|--------------------------|-------------|--------------------------|
| <u>Source</u> | <u>Sink</u> | <u>Volume per hour</u> |
| 1 | 2 | 0.069 |
| 2 | 1 | 0.024 |
| 2 | 3 | 0.026 |
| 3 | 2 | 0.012 |
| 3 | 4 | 0.025 |

Oxidation Rate of Biochemical Oxygen Demand (BOD)

The effluent discharged by the canneries into the harbor carried a high organic load. This was measured as BOD (Biochemical Oxygen Demand), the concentration of oxygen (mg/l) necessary to oxidize the material in the water (APHA, 1975). Commonly the change in oxygen in a bottle is measured over a five-day period (a five-day BOD). This is approximately equal to the total amount of oxidizable material, although it can be an underestimate if the oxidation rate is slow.

The actual oxidation rate, or oxygen demand per unit time (K) exerted by the BOD, is a parameter essential to the model. Since no previous data existed at this site, determinations were made on several dates of the oxidation rate for water from several stations in the Los Angeles Harbor (Appendix A). The results of this work indicated that at both 15 and 20C the mean instantaneous daily oxidation rate equaled about 0.5 (Table A.1, in Appendix A), which is equivalent to an instantaneous hourly rate of 0.021. This equaled approximately 2% of the standing stock of BOD oxidized every hour. The equation representing this process is as follows:

$$BOD_t = BOD_0 e^{-BODK \cdot t}$$

where BOD = levels of BOD at time zero and "t" hours later

e = base of natural logarithm

BODK = instantaneous hourly rate of BOD oxidation

t = time in hours

The oxidation of organic matter decreases the BOD by using up oxygen. Since the units for BOD and dissolved oxygen concentration are both expressed as milligrams per liter (ppm), for each time step in the model the decrease in BOD was directly translated into a decrease in dissolved oxygen.

Although we anticipated finding lower oxidation rates at 15° than at 20°C, the data do not indicate such a trend (Appendix Table A.1). More determinations of the oxidation rate coefficient, "K", at lower temperatures are necessary to verify this finding, but at present it seems adequate to represent the oxidation rate in all elements by a single term. If further data justify varying K with temperature, it is a very straightforward process:

$$BODK = K_0 e^{rt}$$

where BODK = fraction of BOD oxidized every hour at a given temperature

K₀ = hourly fraction of oxidized BOD at 0C (extrapolated from findings at high temperatures)

e = base of natural logarithm

r = constant designating the trend with temperature

t = degrees centigrade

Benthic Oxygen Demand

The sediment of the harbor exerts an oxygen demand on the overlying water because of continuous respiration of flora and fauna, and by chemical oxidation, which becomes accentuated by the stirring of the sediment. Since it is very difficult to make reliable in situ measurements of the benthic demand, estimates used in the harbor oxygen model are based on two sources:

- 1) Published values for non-stirred in situ oxygen uptake by sediments (Table 3).
- 2) Data from the harbor (Chen and Lu, 1974) on the Chemical Oxygen Demand of stirred sediments.

Table 3. Oxygen Uptake by Benthic Systems

| <u>System</u> | <u>Temperature</u> | <u>Oxygen Uptake</u> <u>gm O₂/m².hr⁻¹</u> | <u>Reference</u> |
|--|--------------------|---|---|
| New England, salt marsh | 15-20°C 5-10°C | 0.09-0.13 0.04-0.08 | Nixon and Oviatt, 1973 |
| Several fresh water and marine systems | 20°C | 0.07 av. | Hargrave, 1969 |
| Intertidal sand flat | 20°C | 0.07-0.14 | Pamatmat, 1968 |
| USC dock Wilmington Los Angeles Harbor | 15°C | 0.08 [±] -0.04 | Hammond (pers.comm., Univ. So. Cal.) |
| Narragansett Bay | 2-24°C | 0.01-0.1 | Nixon, Oviatt, and Hale, 1976 |

Most of the measurements of oxygen uptake by sediments in Table 3 were conducted in locations that were less eutrophic than Los Angeles Harbor. Since one would expect that rates in the harbor might be higher, a rate of 0.1 g O₂/m².hr at 20°C was chosen to be a reasonable estimate for intact harbor sediments. The effect of temperature on benthic metabolism is an established phenomenon. Therefore the model was written to allow the benthic oxygen uptake to vary as a function of temperature. For every 10°C change in temperature the benthic demand was changed by a factor of two.

The oxygen uptake associated with the oxygen demand of stirred sediments was also included in the model. For stations near the modeled region, Chen and Lu (1974) found that 10 grams of resuspended harbor sediment dropped the dissolved oxygen in the water on the average 4 to 7 mg/l. If 5% of the sediment was resuspended daily to a depth of 10cm, this would result in resuspended sediment oxygen demand of about 0.15 mg O₂/m².hr, slightly more than the estimate for intact sediments at 20°C. Although more precise determinations of the benthic oxygen uptake are possible, preliminary results of the oxygen model indicated that the benthic demand was not nearly as important as the other processes that were included (see section on sensitivity analysis and Appendix C, Fig.C7). For this reason further refinements were not considered necessary.

Air-Water Exchange

There is constant diffusional transport across the air-water boundary, which attempts to restore equilibrium between the two systems. During times of low dissolved oxygen in the water there is a flux of oxygen into the water from the overlying atmosphere, and when the oxygen in the water is supersaturated there is a net flow out. The formulations used in quantifying this process for the model are based on current theory about gas exchange across the air-water interface. Several references were consulted in developing this formulation (Kanwisher, 1963; Liss, 1973; Broecker and Peng, 1974; Emerson, 1975).

Fick's law of diffusional transport describes the gas exchange process as follows:

$$F = D (C_s - C_o) / Z$$

where F = rate of transfer $\mu\text{g}/\text{cm}^2\cdot\text{hr}$

D = molecular diffusivity of the gas, cm^2/hr

C_s = saturation concentration of the gas, parts per million

C_o = observed concentration of the gas, ppm

Z = stagnant boundary thickness of air-water interface, cm

The molecular diffusivity, D , for oxygen is a function of temperature. Over the range 10-25C the relationship can be approximated very well by the following equation:

$$D = 0.0377 + 0.00186 \text{ Temperature, } C$$

The saturation level of oxygen in water is a function not only of temperature but also salinity. Truesdale et al. (1955) investigated this relationship and found the following:

$$C_s = 14.161 - 0.3943T + 0.007714 T^2 - 0.0000646 T^3 \\ - S(0.0841 - 0.00256 T + 0.0000374 T^2)$$

where C_s = the oxygen saturation level, parts per million

T = temperature, Centigrade

S = salinity, parts per thousand

The "stagnant film theory" hypothesizes that the diffusion rate is inversely proportional to the thickness of a hypothetical stagnant film, through which the gas must diffuse. The thickness of this film has been empirically determined to be approximately inversely proportional to the square of the wind speed. The relationship used in the oxygen model is based on observations:

$$Z = 0.28/W^2$$

where Z = stagnant boundary, cm
 W = wind speed, m/sec

Therefore, it is possible to calculate the net air-water exchange of oxygen per unit time, knowing the wind speed, temperature, salinity, ambient dissolved oxygen, and depth of the water. The wind speed often is not constant throughout the day, but generally demonstrates sinusoidal fluctuations with a midday maximum and nighttime minimum (Fig. 3). This diurnal pattern is included in the model, using input data to set the daily maximum and minimum.

In addition to the theoretical formulation of air-water exchange it is possible to measure the rate of diffusion directly, using an airtight dome which is filled with oxygen-free gas to lower the level of oxygen in the air in the dome. The oxygen concentration within the dome is then monitored over a period of several hours as the oxygen diffuses out of the water. Knowing the concentration of dissolved oxygen in the water, the temperature and the salinity, it is possible to calculate the rate of oxygen diffusion (Hall, Day, and Odum, unpubl. MS., as modified by Roques and Nixon, Univ. Rhode Island). Wind speed data makes it possible to compare results from the dome measurements with predictions based on the stagnant film theory. Comparisons based on preliminary results from dome measurements in the harbor are quite favorable (Appendix B). Additional dome measurements need to be made at lower and higher wind speeds to verify that Fick's law is applicable over a variety of environmental conditions.

Phytoplankton

Because the goal of this model was to be a practical management tool, it was decided that the effect of microscopic algae (phytoplankton) would be more precise if the formulation relied heavily on empirical data for phytoplankton biomass and production. To formulate a truly predictive phytoplankton sub-model would have required a more thorough knowledge of harbor plankton physiology than exists currently. A generalized self-generating phytoplankton formulation based on the standard inputs of temperature, light, and inorganic nutrients would have limited application in the organically rich and very complex harbor system under consideration. Therefore, a more direct approach was used, which makes an assessment of the influence of phytoplankton on dissolved oxygen based on observed algal biomass and photosynthesis. Records for monthly measurements were available for the area (Oguri, 1974).

Phytoplankton increase the concentration of dissolved oxygen in the water by fixation of carbon into organic matter, but their photosynthesis occurs only during the light, and it is affected directly by light

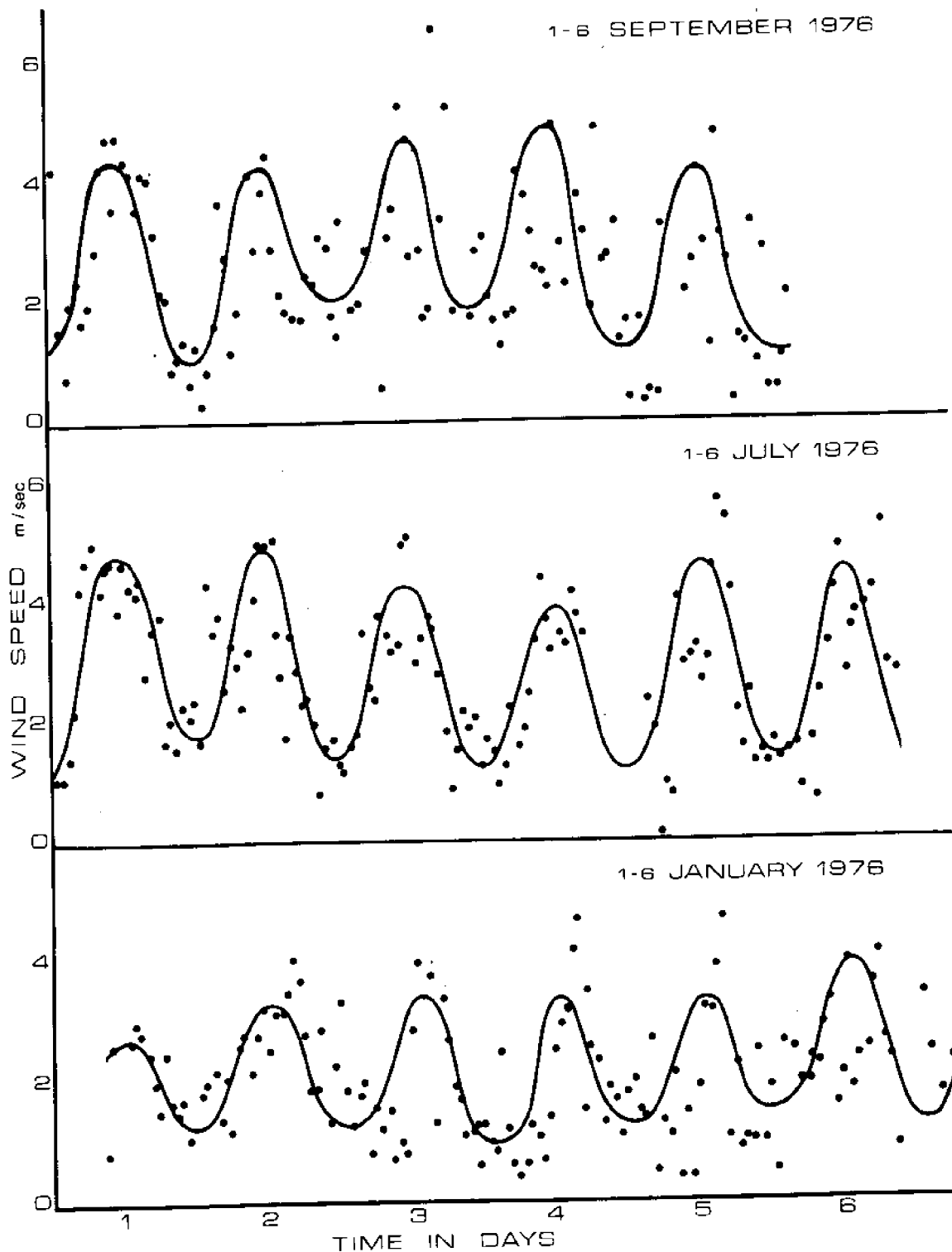


Figure 3. Hourly wind speed data for three six-day periods during 1976. These data generally demonstrated midday maxima and night-time minima, and were satisfactorily fitted with a sine curve of variable amplitude (solid line).

intensity. The rate of photosynthesis demonstrates a diurnal pattern which can be approximated by a truncated sine wave (Fig. 4). Given a value for the rate of maximum photosynthesis for the water column, as input, the model predicts the photosynthesis throughout the day, and calculates the influence of this oxygen production on the dissolved oxygen in the water.

In addition to their role as oxygen producers, phytoplankton also consume oxygen by respiration. This proceeds both in the dark and in the light. The treatment of phytoplankton respiration in the model is a simple function of temperature and biomass (expressed as chlorophyll a), and ignores complicating factors like photorespiration and interspecific differences.

The single equation which is used for phytoplankton respiration is based on studies of several species of phytoplankton, acclimated to a variety of temperatures (Ryther and Guillard, 1962):

$$r_t = r_0 e^{st}$$

where r_t = respiration rate at temperature, t

r_0 = respiration rate at zero degrees

0.435 g O₂/hr/g Chl a extrapolated from several values at higher temperatures

e = base of the natural logarithm

s = expression of trend of respiration and temperature,

0.069 = a Q₁₀ of 2

t = temperature, °C

Ryther and Guillard reported that at 5°C *Skeletonema costatum*, *Thalassiosira pseudonana* (*Cytotella nana*) and *Detonula confervacea* all respired at about 0.23 g carbon/hr/g Chl a. This is equivalent to 0.61 g O₂/hr/g Chl a. Using their results, the appropriate r_0 in the above equation is 0.435g O₂/hr/g Chl a.

Using the available input values for temperature and phytoplankton biomass (Chlorophyll a), the model calculates an appropriate phytoplankton respiration rate and evaluates the effect of this oxygen consumption in the total balance. Because of the diurnal patterns in phytoplankton production and wind speed, the "steady state" oxygen budget shows a daytime high and nighttime low. It is important to keep this pattern in mind when considering that field data is usually collected about midday, so probably represents maximum oxygen values.

After the immediate steady-state oxygen budget is calculated by the model, an estimated phytoplankton growth rate is calculated as the difference between the total photosynthesis for the day and the respiration.

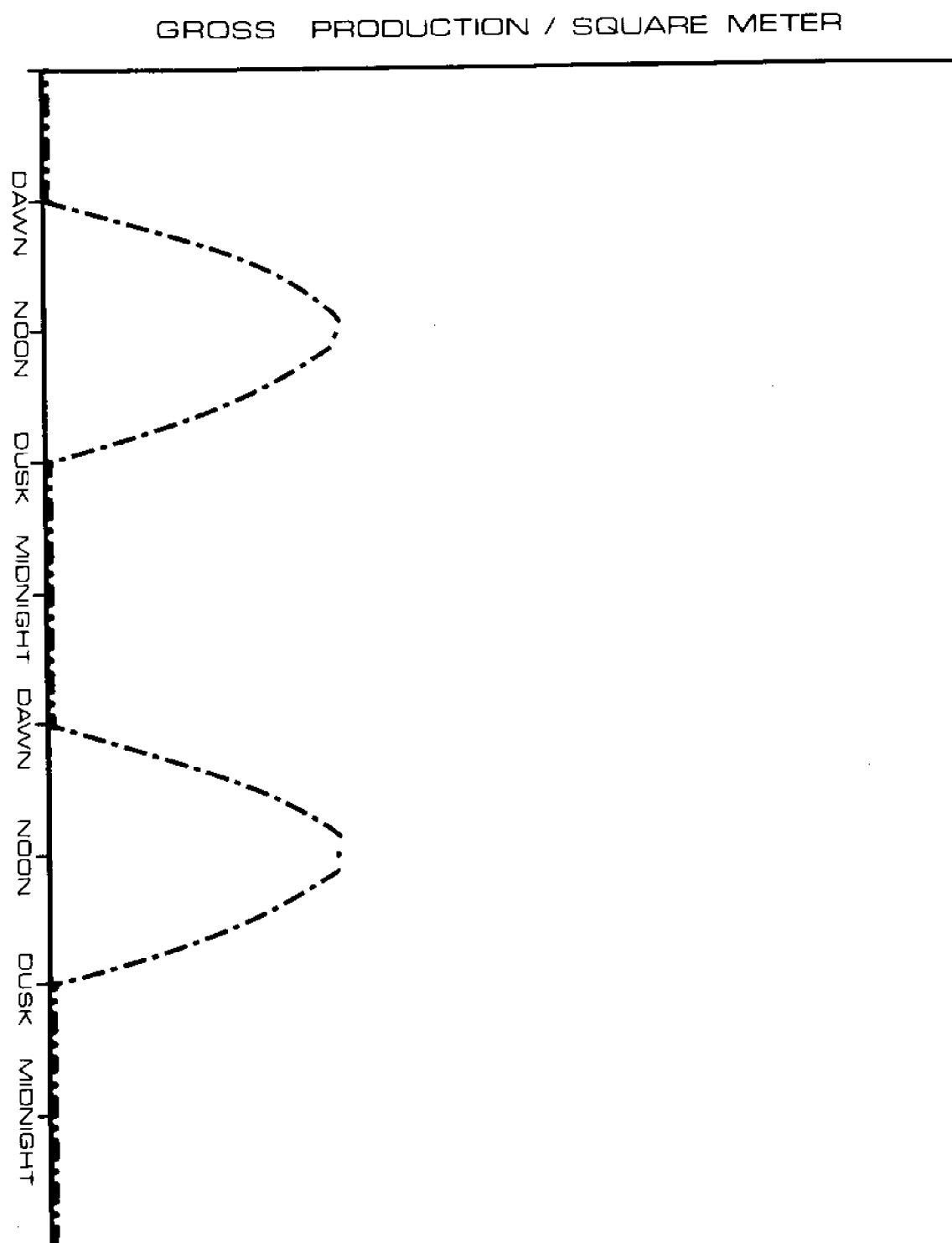


Figure 4. Phytoplankton gross production was simulated using a truncated sine wave with a noontime maximum, and a value of zero from dusk to dawn.

$$\text{Growth} = \text{Photosynthesis (daytime)} - \text{Respiration (24-hour)}$$

The units are converted from grams of O_2 to the equivalent amount of carbon, and Chlorophyll a to get an estimate for the daily fractional biomass increase. A carbon to Chlorophyll a ratio of 50:1 by weight is used (Eppley *et al.*, 1971) and an oxygen to carbon conversion of 0.38 is based on the atomic weight ratio in CO_2 (12g carbon vs 32g oxygen).

$$N_T = N_O e^{rt}$$

where N_T = new biomass

N_O = current biomass

e = base of natural logarithm

r = $\ln(1.0 + \text{growth rate per day})$

t = time, in days

Since this calculation ignores phytoplankton mortality, it will lead to an overprediction of the future phytoplankton biomass. As a consequence, the model prediction is undoubtedly more extreme than the real world. This is not viewed as a serious weakness in the model, since it is better to plan too conservative a management strategy than to exceed the assimilation capacity of the receiving waters. The new biomass is used to calculate a new rate of production based on the earlier assimilation ratio (productivity per unit biomass).

Finally, a test is made in the model of the consequences of a sudden die-off of the entire phytoplankton biomass. The biomass is added as its equivalent amount of BOD and a calculation is made of the effect on the dissolved oxygen.

Taken together, the series of model runs makes it possible to examine fairly rapidly the ramifications of varying degrees of organic loading on the oxygen level for a number of potentialities.

RUNNING THE MODEL

Input

In order to operate the oxygen model it is necessary to enter values for several factors. These include temperature, salinity, wind speed (maximum and minimum), BOD loading from canners and Terminal Island Treatment Plant sewage facility, the dissolved oxygen level in the effluent, and an estimate for the oxygen and BOD outside the model area. Also included are data for phytoplankton biomass (mg Chl A/ m^3 entered for each element), and an estimate of the maximum photosynthesis for

the water column ($\text{g O}_2 \text{ produced/m}^2 \cdot \text{hr}^{-1}$). Values for the rates of circulation, BOD oxidation and benthic oxygen demand can also be entered explicitly. Although they do not affect the results, initial conditions are also required for oxygen and BOD. It is also necessary to supply information on the desired length of simulation, output interval, and time step.

The Standard Run

A first phase of testing a model's validity is to choose representative input values and to see if the model's predictions are reasonable. Table 4 gives the input parameters chosen for the standard run.

There are abundant data on seasonal values for temperature and salinity. Temperatures have been observed to range from 8 to 23°C and salinities from 32 to 37‰ (Soule and Oguri, 1974, 1976a). 20°C and 34 ppt were considered as representative of the area for the standard run.

Wind speed in the harbor had a pronounced diurnal variability, with high velocities occurring around midday and lows at night (Fig. 3). This pattern has been represented in the model by a sine curve, using input values for the maximum and minimum. Wind data was obtained from the environmental monitoring program conducted at the Southern California Edison Plant in Long Beach Harbor, within a few kilometers of the model study area. Summaries from 1975 were available from their annual report (EQA/MBC, 1975; tables 4-1 and 4-2). A complete record of hourly wind velocities was obtained for 1976 from Southern California Edison, and a representative sample of these data appears in Fig. 3. These records show that the wind speed exceeds 5 meters/second only a small fraction of the time. Although in the harbor the wind often drops to less than 1 m/sec at night, a minimum of 2.0 was used in the model's standard run. This slight overestimate is necessary because the air-water exchange, as calculated by the Fick's law equation, varies as a square of the wind speed and has been shown to underestimate diffusion at low wind speeds (Emerson, 1975).

The BOD loading from the cannery has been quite variable depending on the fishing catch. The discharge ranged from zero to more than 30 million gallons per day, with an average BOD content of about 1,000 mg/l. Using data from the fish cannery waste water monitoring reports (Regional Water Quality Control Board, unpublished data), it was possible to calculate the average grams BOD per hour discharged. In 1973 the average discharge was 1.27×10^6 grams BOD/hour. In 1974 the loading dropped to about half this level (av. 6.4×10^5) and continued at approximately that rate. For the standard run a cannery loading of 7.0×10^5 grams BOD/hr was chosen to represent average conditions.

Prior to the completion of the secondary sewage treatment facility at Terminal Island (TITP) high BOD discharge was also coming from primary treated sewage. A summary from the City of Los Angeles Department

of Public Works reported the 1974 TITP average discharge was 10.3 MGD with an average BOD content of 150 mg O₂/l. A telephone conversation with Mr. Jeff Naumann at TITP confirmed this past year that prior to secondary treatment operation this discharge and BOD still applied. It is equivalent to a discharge of 2.5×10^5 g BOD/hr, and was used to represent the TITP effluent in the standard run.

Table 4. Input Values for the Standard Run

| <u>Factor</u> | <u>Value</u> |
|---------------------------|--|
| Temperature | 20° C |
| Salinity | 34 ‰ |
| Wind speed | high - 6 m/sec low - 2 m/sec |
| Cannery BOD loading | 7×10^5 grams BOD/hour |
| TITP BOD loading | 2.5×10^5 grams BOD/hour |
| Phytoplankton | |
| biomass | 5 mg Chl. A/m ³ |
| maximum photosynthesis | 0.3 g O ₂ /m ² /hr |
| Benthic oxygen demand | 0.2 g O ₂ /m ² /hr |
| BOD oxidation rate | 0.015 fraction oxidized per hour |
| Mixing coefficient factor | 1.5 |

For the past seven years the Harbors Environmental Projects have been monitoring phytoplankton standing stock (chlorophyll *a* and primary production ¹⁴C uptake under constant light at several stations in the harbor (Oguri, 1974). The chlorophyll *a* concentration used as input for the standard run (5 mg Chl A/m³) represents an estimate for non-bloom conditions. It is equivalent to about half the annual mean for 1973 in that region of the harbor and is about equal to the 1974 annual mean (Allan Hancock Foundation, 1976).

In order to standardize measurements of primary production, samples were incubated under constant artificial light in special productivity chambers. (For more detailed description of methods see Oguri, 1974). To convert these productivity measurements into oxygen units expressing

the maximum water column photosynthesis, it was necessary to make appropriate conversions. A single field measurement helped relate these past data to the type of input necessary to run the model. Light and dark bottles were incubated simultaneously in situ in a vertical array and in the incubation chambers. Oxygen changes in the dark and light bottles determined net and gross primary productivity (Strickland and Parsons, 1972).

This calibration incubation was done during the middle of the day so that the in situ vertical array represented the maximum production (Fig. 5). Integrating the results over the entire water column, calculations showed that the total water column photosynthesis was equivalent to 0.33 grams $O_2/m^2/hr$, for a phytoplankton standing stock of about 2 mg Chl A/ m^3 . The results from the incubation boxes indicated a photosynthetic rate of about one-half the in situ array. Since the photosynthetic rate is strongly affected by light intensity which is constantly changing in nature, the relationship between the two methods is certainly not constant. It is therefore impossible to apply an arbitrary conversion factor. In addition to light variability, other factors which result in changing assimilation ratios (production per unit chlorophyll), would influence the relationship between in situ and incubation box results.

To assess the range of this variability, as well as determine in situ production rates, it is necessary to conduct several more incubations comparing the two methods. Since Fig. 5 represents the only calibration to date, a value of 0.3 grams $O_2/m^2/hr$ is used in the model's standard run. This production value used as input to the model is meant to represent the daily maximum, while the ^{14}C results from the incubation boxes are intended to be daily averages.

The value in the standard run for the benthic oxygen demand is taken directly from summing the estimates for intact and resuspended sediments. In order to run the model it is necessary to include values for dissolved oxygen and BOD in the water surrounding the region designated by Fig. 1 and Table 1. In routine use of the model these data would be part of the monitoring program. For the standard run it was assumed that these waters contained a BOD level of 2 mg/l and an oxygen content equal to saturation for the specified salinity and temperature inputs. Admittedly these values are arbitrary and are not necessarily realistic.

Model Recalibration

The estimate derived from empirical data for the oxidation rate of BOD (0.02) resulted in abnormally low oxygen levels as compared to observed oxygen levels. Decreasing the value by 25% yielded better results, so the lower value was used in the standard run. Currently there is no experimental data to support the choice of this new value, but earlier data may have been biased high because only low BOD

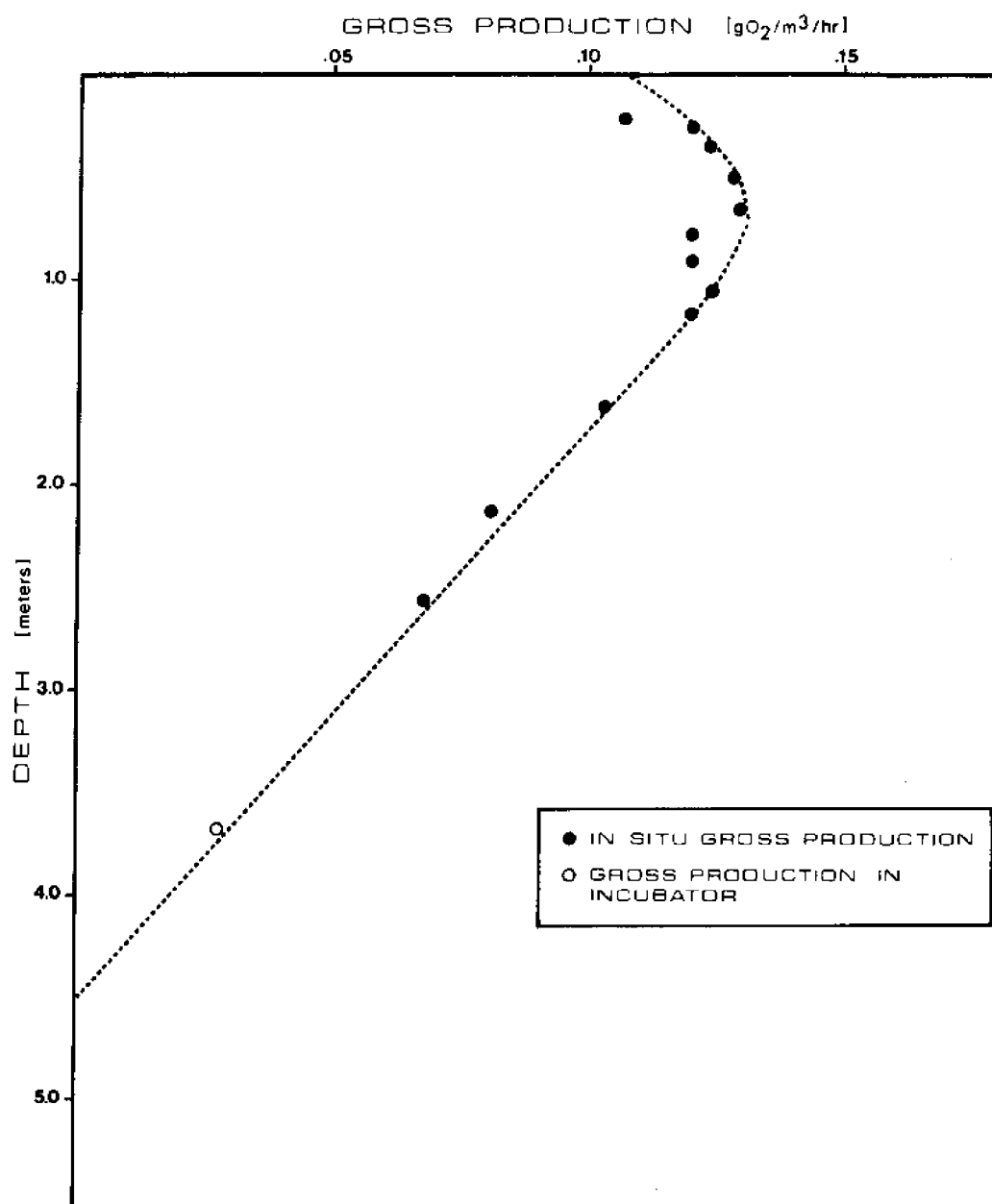


Figure 5. Gross primary production ($\text{g O}_2/\text{m}^3/\text{hr}$) vs. depth (m) measured in situ using the light-dark bottle method. The gross production integrated for the water column was $0.3 \text{ g O}_2/\text{m}^2/\text{hr}$ for a 4.6 hour midday incubation on November 10, 1977. Standing stock of Chlorophyll *a* = $2 \text{ mg}/\text{m}^3$.

water was tested. Similarly, the exchange coefficients were adjusted for the standard run. When exchange coefficients based on the dye study (Table 2) were increased by 50% the output seemed more stable and reasonable. This alteration is justified on the basis of the uncertainties associated with the derivation of the values in Table 2.

RESULTS

Results for the Standard Run are given in Table 5. The range between maximum and minimum in the oxygen levels for Table 5A is due to the combined effect of diurnal fluctuation in photosynthesis and wind speed, and may be of greater amplitude than usually occurs in this area. The exact values for predicted dissolved oxygen should not be interpreted too literally. The important feature is that the values for the three elements are reasonable and show the same trend as is exhibited in the field.

In addition to predictions for the dissolved oxygen levels, the model output includes steady state values for BOD in the three elements and a calculation of the relative fluxes for the various processes included in the oxygen budget. The results for the Standard Run (Table 5B) show the dominance of BOD oxidation in the flux of oxygen, and imply its overwhelming importance in the total budget. Of course, different input values for production, wind, etc., change the relative importance of the various processes, but in all the sensitivity runs, except those testing BOD loading directly, BOD oxidation remained the largest flux.

Example of Phytoplankton Growth and Crash

The model calculates the phytoplankton net growth rate (gross production minus respiration) from inputs on biomass and maximum daily gross production. Using this growth rate it is straightforward to calculate an estimate for the biomass N days later. For the standard run the model predicts a fractional growth rate of 0.87 for the plants in element 1. If the biomass on day 1 equaled 5.0 mg Chl.A/m^3 then the biomass ten days later would be $2614 \text{ mg Chl.A/m}^3$, an unreasonably high value. Although the 0.87 is not unrealistic for phytoplankton growth alone, it does not take into account phytoplankton mortality (e.g., by zooplankton grazing) or a feedback from nutrient limitation, so it is a gross overestimate for actual biomass increase. Because of these limitations, the model is unable to make a reasonable growth prediction and again must rely on empirical data from a monitoring program.

As an example, assume that the net phytoplankton growth (after mortality) equals 45% per day in all three elements. If on day 1 the phytoplankton biomass is a uniform 5.0 mg Chl.A/m^3 , then ten days later the biomass would be 41 mg Chl.A/m^3 in all elements. If that biomass were to die suddenly the result would be to increase the BOD loading and

Table 5. Results of Standard Run.

A. The diurnal range for steady state values of dissolved oxygen, mg/l.

| <u>Element</u> | <u>1</u> | <u>2</u> | <u>3</u> |
|----------------|----------|----------|----------|
| minimum | 1.9 | 3.2 | 5.6 |
| maximum | 4.8 | 5.2 | 6.4 |

B. Percentage of total oxygen flux contributed by processes

| <u>Element</u> | <u>1</u> | <u>2</u> | <u>3</u> |
|--------------------|----------|----------|----------|
| Air-water exchange | 15 | 16 | 13 |
| BOD oxidation | 62 | 64 | 50 |
| Primary production | 3 | 4 | 9 |
| Advective mixing | 13 | 10 | 9 |
| Demand of benthos | 7 | 6 | 19 |

Table 6. Phytoplankton Biomass Crash

A. Before crash: phytoplankton biomass = 4/mg Chl A/m³

| <u>Element</u> | <u>1</u> | <u>2</u> | <u>3</u> |
|----------------|----------|----------|----------|
| oxygen maximum | 6.4 | 6.8 | 7.7 |
| oxygen minimum | 2.5 | 3.8 | 5.9 |
| BOD | 33.8 | 19.5 | 6.5 |

B. After crash: phytoplankton biomass = 0 mg Chl A/m³

| <u>Element</u> | <u>1</u> | <u>2</u> | <u>3</u> |
|----------------|----------|----------|----------|
| oxygen maximum | 4.3 | 4.8 | 6.0 |
| oxygen minimum | 1.2 | 2.4 | 5.1 |
| BOD | 39.0 | 24.7 | 11.4 |

subsequently depress the oxygen. Table 6 shows the results from the model for this example. The increase in BOD is appreciable enough to cause a depression in the oxygen of 1-2 ppm. If this drop in oxygen were large enough it might set off a chain reaction of mass mortality among aerobic organisms, which would further increase the BOD level and drive the system anoxic. Careful monitoring of the phytoplankton biomass and ambient oxygen levels combined with measurements of net biomass increase in phytoplankton community and application of a budget model such as this one, could assist in preventing dramatic bloom-crash conditions.

Sensitivity Analysis

A vital part of the formulation of any mechanistic model, such as this one, is the systematic variation of a single factor at a time, to test the effect on the results. This "sensitivity analysis" pinpoints the variables which are the most critical. Graphs of sensitivity runs for eight different variables are presented in Appendix C. Again, the precise values are not nearly as important as the overall trends and shapes of the maximum and minimum lines for each element. Using the model to predict precise values would only be possible after an opportunity for additional feedback from monitoring data and model tuning, which has not been possible in this study. But these results do show some important points.

The overriding importance of the BOD loading on the level of dissolved oxygen is obvious (Appendix Fig.C.2). The cannery discharge is reflected by the BOD levels in the receiving waters. Model predictions for BOD in the various elements for a range of loadings (Table 7) are consistent with direct measurements of BOD at the sixteen stations in this area monitored biweekly for the Tuna Research Foundation prior to the hookup into the Terminal Island Treatment Plant. For one series of runs, the model was modified so that all the cannery effluent would be discharged during the day (8 a.m.-8 p.m.) instead of evenly throughout the 24 hours. Although this modification introduced some diurnal variability into the BOD concentration, for conditions of the standard run there was surprisingly little change in the simulated levels of dissolved oxygen (less than 0.2 mg/l).

The rate at which the BOD is oxidized is a critical variable (Fig. C.6). Changing the value from 0.02 to 0.015 for the standard run raised the minimum value for element 1 from 0.7 to 1.9 mg/l. The oxidation rate also directly affects the BOD in the receiving waters (Table 8). Although the wind speed is another critical parameter, the process of air-water oxygen exchange is large only in response to depleted conditions caused by high BOD. The sensitivity of the model to the diurnal amplitude of wind speed (Fig. C.4) is dramatic, and points up the need for an accurate formulation for wind and adequate baseline data.

For a constant assimilation ratio (productivity per unit biomass) an increase in phytoplankton biomass and production had a fairly small

FORMULATIONS FOR MAJOR PROCESSES

Physical Mixing

The determination of the mixing rate of water between elements for the model is based on empirical data, not derived from theoretical principles. Exchange coefficients between elements were calculated from the results of dye studies in this region of the harbor (Foxworthy, 1973). In order to make the necessary calculations, two assumptions were necessary:

1. The levels of dye observed in the study represented steady state conditions. That is, concentrations of dye of various stations in the water would no longer continue to increase appreciably with time, if dye was continually added to the effluent at the same rate.
2. The volume of the elements remained constant over time. (This necessitated ignoring the effect of tide on the volume). Tidal effects on overall mixing were already incorporated into the dye observations.

With these assumptions (and their inherent limitations) we can proceed to calculate the exchange coefficients between elements using a mass balance approach. The data of Foxworthy (1973) showed that the dyed effluent was at a concentration of 0.5 gm/m^3 and a discharged volume of about $1000 \text{ m}^3/\text{hour}$. This represented a mass input of 500 g/hr of dye into Element 1. His data also showed Element 1 had an average concentration of dye of about 0.05 g/m^3 , Element 2 about 0.03 g/m^3 , and Element 3 about 0.01 g/m^3 . Using the steady-state concentration and constant volume assumptions, the following calculation can be made:

INPUT (into Element 1 from effluent and Element 2)
= OUTPUT (into Element 2 from Element 1)

assuming constant mass: $500 \text{ g} + 0.03 \text{ g/m}^3 \times X = 0.05 \text{ g/m}^3 \times Y$
assuming constant volume: $1000 \text{ m}^3 + X = Y$

where $X = \text{m}^3$, volume of water from Element 2 to Element 1
 $Y = \text{m}^3$, volume of water from Element 1 to Element 2

Solving these equations:

| | |
|--|-----------------------------|
| $X = 2.25 \times 10^4 \text{ m}^3/\text{hr}$ | 6.9% of volume of Element 1 |
| $Y = 2.35 \times 10^4 \text{ m}^3/\text{hr}$ | 2.4% volume of Element 2 |

Similar calculations were made to determine the fractional exchanges from

Table 7. BOD concentration (mg/l) in each element at various cannery loading rates*

| Cannery discharge (grams $\times 10^5$ BOD/hr) | Element | | |
|---|----------|----------|----------|
| | <u>1</u> | <u>2</u> | <u>3</u> |
| 3.5 | 18.7 | 12.1 | 4.4 |
| 7.0 | 34.8 | 20.3 | 6.7 |
| 14.0 | 63.1 | 33.0 | 10.1 |

*TTP discharge constant at 2.5×10^5 grams/hr. All other variables constant at values used for standard run (Table 4).

Table 8. Effect on BOD load in water of varying the BOD oxidation rate*

| BODOX | Element | | |
|----------------------|----------|----------|----------|
| | <u>1</u> | <u>2</u> | <u>3</u> |
| 0.005 | 42.9 | 26.1 | 9.2 |
| 0.01 | 38.3 | 23.0 | 7.8 |
| 0.015 (std. run) | 34.8 | 20.3 | 6.7 |
| 0.02 (av. Table A-1) | 30.4 | 16.8 | 5.4 |
| 0.025 | 27.5 | 14.7 | 4.5 |

*All other variables constant at values used for standard run (Table 4) (Concentrations of dissolved oxygen given Fig. C.6, Appendix C).

effect on the dissolved oxygen (Fig. C.5). In order to get the super-saturated oxygen levels observed in these waters it would be necessary to have a higher assimilation ratio than that chosen for the standard run. Since the model requires actual measurements of the productivity and biomass, the artificiality of the constant assimilation ratio would not be a problem in real implementation of the model.

CONCLUSION

At this stage it is still not possible to evaluate adequately this oxygen model as a useful management tool. Since the canneries are now required to discharge through the Terminal Island Treatment Plant, it has been impossible to "fine tune" the model to assess its accuracy or to test its reliability. Historical data are insufficient to make the necessary rigorous comparisons between model predictions and reality, but based on the results of the standard run and sensitivity analyses, the model seemed to respond quite reasonably. For other locations with high BOD discharge a similar approach could be valuable in determining the assimilation capacity of the receiving waters.

One of the strengths of the model is the incorporation of results from the localized area in the generalized equations for the oxygen dynamics. Spatial heterogeneity, although simplistic, is another strength of the model. With more of the right kind of data on the detailed physical circulation this could be further refined to become even more realistic. The scope of the model is by definition narrow. Since it was intended to be an oxygen model, not an ecosystem model, it included only the processes which affect the oxygen concentration directly. It is fundamentally a budget, not a long-range predictive model, so it is necessary to supply a lot of environmental data as input. In one sense this could be seen as a serious weakness, but it was done intentionally with the hopes of making the model a useful management tool that would be valuable when used in conjunction with environmental monitoring. This model was never conceived to be a panacea, but a rough approximation of reality that would help guide management of discharge. It was designed as a dynamic framework for structuring and ordering of environmental data into a complete oxygen budget to provide a rational synthesis of disparate information. As such, this approach may have real potential in guiding decisions about the kinds of data that are most useful in approaching the particular problem of high BOD discharge into receiving waters such as the Los Angeles Harbor. Much of the effort spent in the development of this model was working on the general equations for the most important processes (*i.e.*, air-water oxygen exchange and rate of BOD oxidation). To apply this model to a different location would not entail a complete reformulation of these important processes, but would involve a careful determination of the particular set of coefficients for the critical rates applying to the new location.

Finally, it should be reemphasized that with further study and application, this model could be refined and improved in many ways. The formulations and results presented here are not intended to be interpreted as a static finished product. It is anticipated that as this model is used it will continue to evolve to become more useful and a better representation of the real world.

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APPENDIX A

BOD OXIDATION RATE

In order to determine the oxidation rate for the organic matter, it was necessary to measure how the oxygen changes with time. In all experiments several 300 ml BOD bottles were filled by siphon from a single sample of unfiltered harbor water. The oxygen in one of these bottles was immediately measured chemically by Winkler titration (Standard Methods, 1975), and the remaining bottles were incubated in the dark within 2C of the ambient harbor surface water temperature. During the following several days the bottles were removed serially from the incubator and the oxygen measured. The difference in dissolved oxygen between the initial reading from the harbor and the level in the bottles over time indicated how rapidly the organic matter in the water was being oxidized. Figure A.1 (a-f) presents these data.

Based on the shape of these curves, it was possible to calculate values for "K", the instantaneous oxidation rate expressed as the fraction of the organic matter (ultimate BOD) oxidized per day. To assist in the calculation of "K", a computer program was written by Mr. Wen-Li Chiang to minimize the least squares difference between a regression curve (with curvature "K") and the data. Table A.1 gives the resulting determinations of "K" for the various sampling dates. Although there is a fair amount of variability, nearly all the values are between 0.3 and 0.7, and the average is about 0.5, indicating that about 50% of the ultimate BOD occurs during the first day.

Table A.1. BOD Oxidation Constants. From surface samples, all sampling dates. (see map, Fig. A.2, station locations).

| <u>Starting Date and Incubation Temperature</u> | <u>Station</u> | <u>BOD Constant "K" (day⁻¹)</u> |
|---|----------------|---|
| Jan. 29, 1976 20°C | A3 | 0.38 |
| | A4 | 0.27 |
| | A7 | 0.68 |
| Aug. 4, 1976 20°C | 4B | 0.46 |
| | G2 | 0.92 |
| | G3 | 0.33 |
| | G4 | 0.49 |
| | G5 | 0.32 |
| | A12 | 0.42 n=9 $\bar{X} = 0.474 (+0.206 \text{ s.d.})$ |
| Feb. 3, 1977 15°C | 1B | 0.497 |
| | 2B | 0.448 |
| | 3B | 0.573 |
| | 4B | 0.657 |
| | 1C | 0.718 |
| | 2C | 0.429 |
| | 4C | 0.732 |
| | 1D | 0.535 |
| | 2D | 0.622 |
| | 3D | 0.431 |
| | 4D | 0.497 n=11 $\bar{X} = 0.558 (+0.11)$ |
| Aug. 18, 1976 20°C | 2A | 0.385 |
| | 2B | 0.335 |
| | 2C | 0.341 |
| | 2D | 0.744 n=4 $\bar{X} = 0.45 (+0.196)$ |

A-1

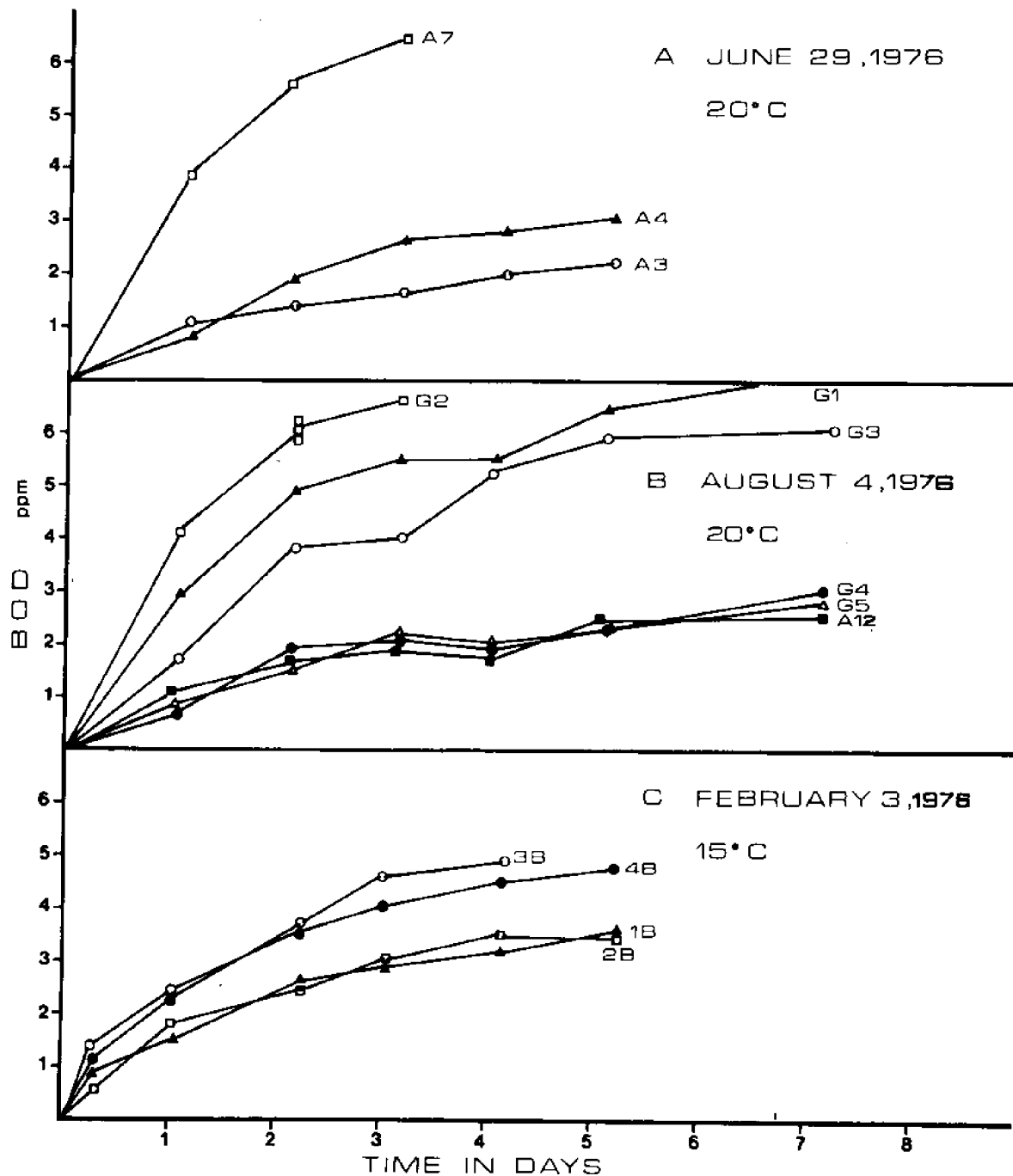


Figure A.1. Oxygen consumption over time showed a similar hyperbolic pattern of increase for whole water samples from various stations and dates.

A-1 CONTINUED

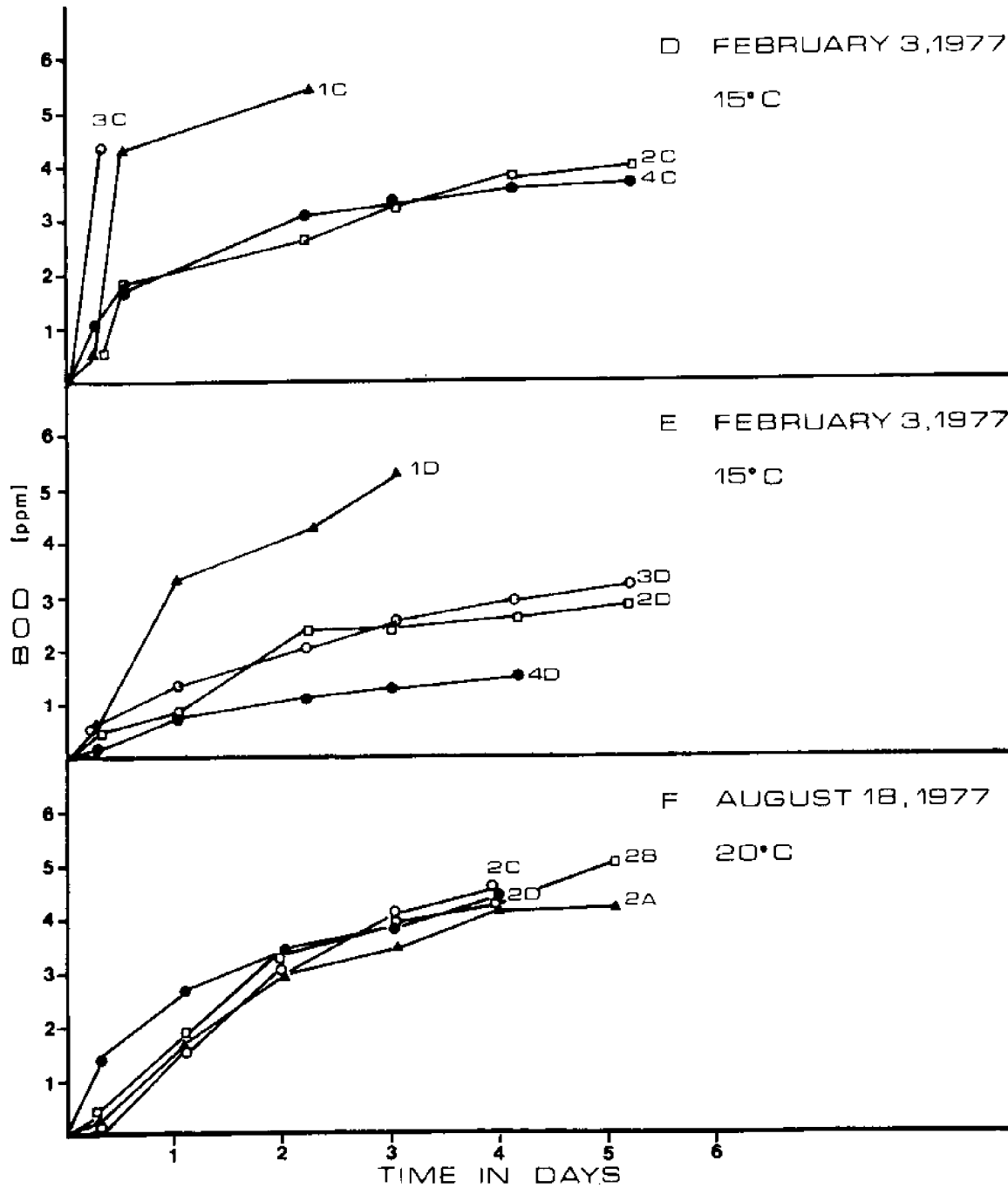


Figure A.1 (continued)

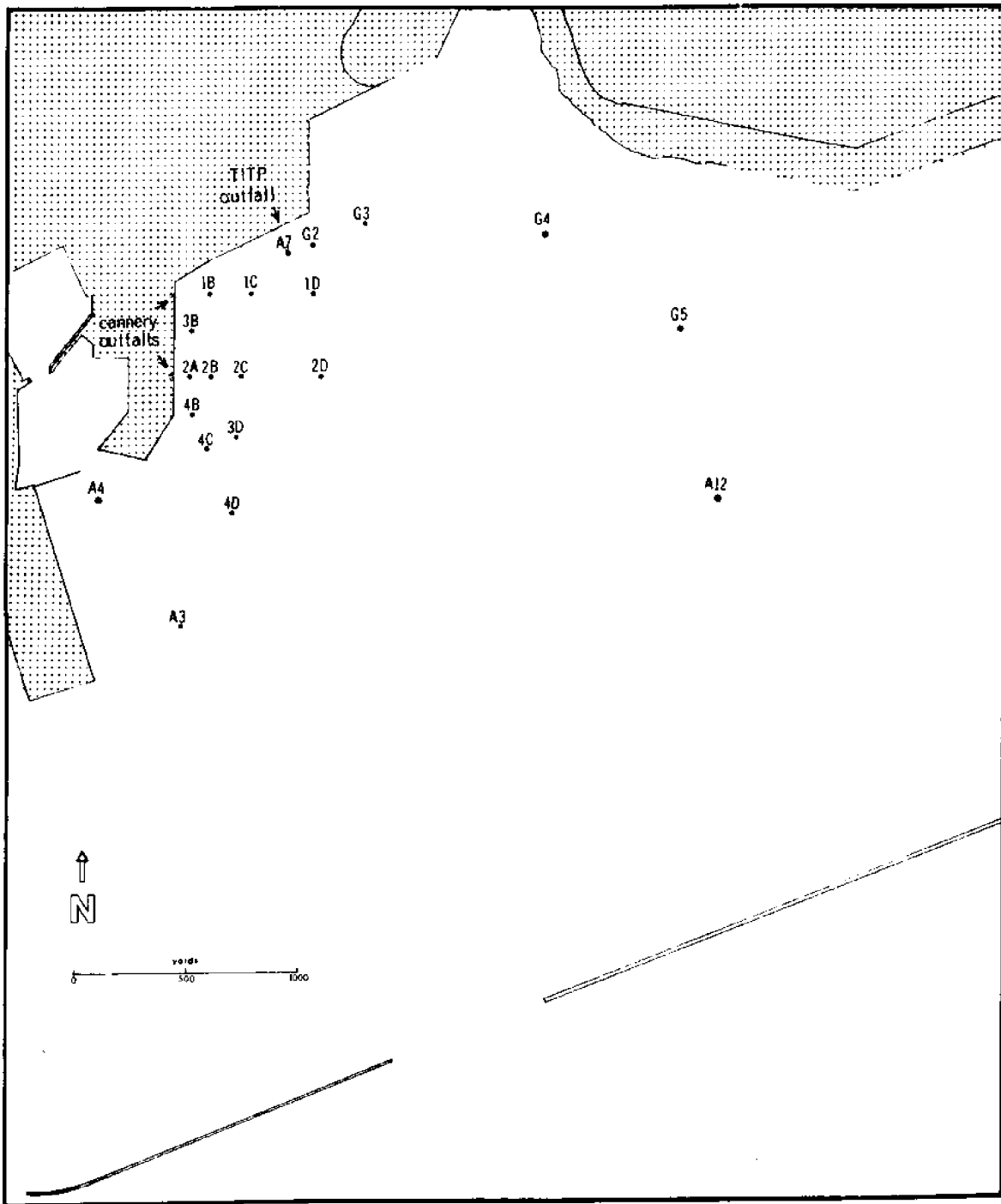


Figure A.2. Map of stations in Los Angeles Harbor sampled when determining the oxidation rate of BOD.

APPENDIX B

COMPARISON OF AIR-WATER OXYGEN DIFFUSION USING FIELD DOME RESULTS AND FICK'S LAW

Field Data. November 4 1977. From USC Dock at Wilmington, Los Angeles
Salinity = 33.5 ppt.

| Time | Water Temperature, C | Dome Oxygen, ppm | Water O ₂ , ppm | Wind, kt |
|------|-------------------------|---------------------|-------------------------------|----------|
| 0840 | 18.2 | 0.12 | 6.03 | < 2 |
| 1030 | 18.7 | 0.2 | 6.62 | 5 |
| 1245 | 19.2 | 0.3 | | 5 |
| 1505 | 20.7 | 0.5 | 6.70 | 8 |
| 1725 | | 0.7 | 7.04 | < 2 |

Note: Fortunately the wind was fairly steady, at about 5 kts for several hours in the middle of the day.

Calculation of Diffusion Constant for the dome used the following formula:

$$K = \frac{V \cdot \rho}{10^3 A \cdot t \cdot P_t} \ln \frac{P_w - P_o}{P_w - P_d}$$

where K = diffusion constant per unit atmosphere deficit

V = volume of dome (1380 ml)

ρ = density of air (1.2 g/l)

A = area of dome (0.017 m²)

t = time elapsed (9 hrs)

P_w = average partial pressure of oxygen in the water:

$$\frac{6.7 \text{ mg/l (observed av.)}}{7.37 \text{ mg/l (saturation value)}} = 0.91 \times 0.209 \text{ (oxygen fraction of the air)} = 0.1900$$

P_o = partial pressure of oxygen in dome at start = 0.0034

P_d = partial pressure of oxygen in dome at end:

$$\frac{0.7 \text{ mg/l}}{7.37 \text{ mg/l}} = 0.95 \times 0.209 = 0.01985$$

P_t = total pressure in dome (1 atmosphere)

For these data, K = 1.0 g O₂ m⁻² hr⁻¹ atm⁻¹.

To determine the actual ambient flux it is necessary to calculate the "saturation deficit," the difference in partial pressure (atmospheres) between the oxygen dissolved in the water (av. 6.7 ppm) and the oxygen concentration in the overlying air (saturation, 7.37 mg/l):

$$\frac{6.7 \text{ ppm (observed in water)}}{7.37 \text{ ppm (saturation)}} = 0.91 \times 0.2091 \text{ atm} = 0.1900 \text{ atm}$$

$$\begin{aligned} \text{Sat Def} &= 0.2091 \text{ (atm. O}_2 \text{ in air; sat.)} - 0.1900 \text{ (av.atm. O}_2 \text{ in water)} \\ &= 0.0191 \end{aligned}$$

$$\text{O}_2 \text{ Flux} = K \times \text{sat def} = 1.0 \times 0.019 = 0.02 \text{ g m}^{-2} \text{ hr}^{-1}$$

Using Fick's law

$$\text{wind} = 5 \text{ Kts} = 3 \text{ m/sec so } Z = 0.031 \text{ cm}$$

$$D = 0.073 \text{ at } 20^\circ\text{C}$$

$$C_s = 7.37 \text{ mg/l}$$

$$C_o = \text{av. } 6.7 \text{ mg/l (range 6.0-7.0 mg O}_2\text{/l)}$$

$$\text{Therefore: } F = 1.58 \text{ } \mu\text{g/cm}^2 \cdot \text{hr} = 0.016 \text{ g m}^{-2} \text{ hr}^{-1}$$

APPENDIX C

RESULTS OF SENSITIVITY ANALYSES

Figures C.1-8. Sensitivity Analysis for Critical Model Parameters.

Maximum and minimum diel values given for each element.
All input values are for standard run except single
factor being tested.

KEY:

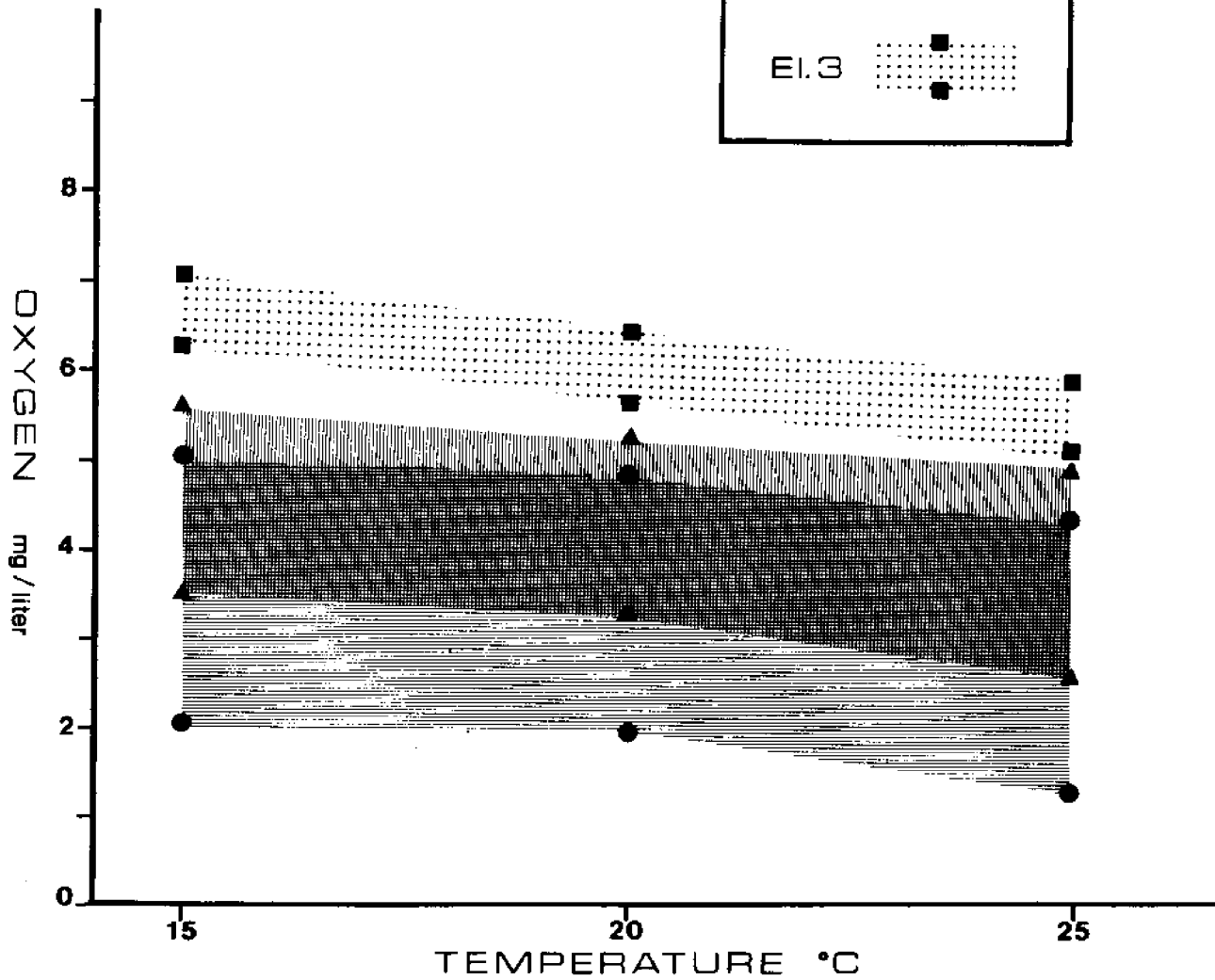
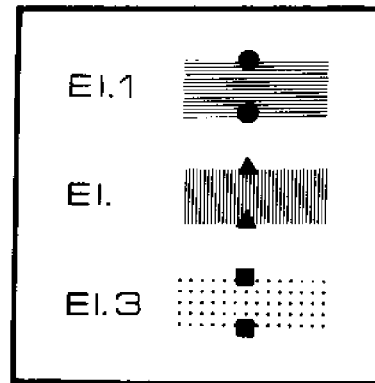


Figure C.1. Higher temperatures caused a slight depression of oxygen. Diel range for element 1 greater than for 2 or 3.

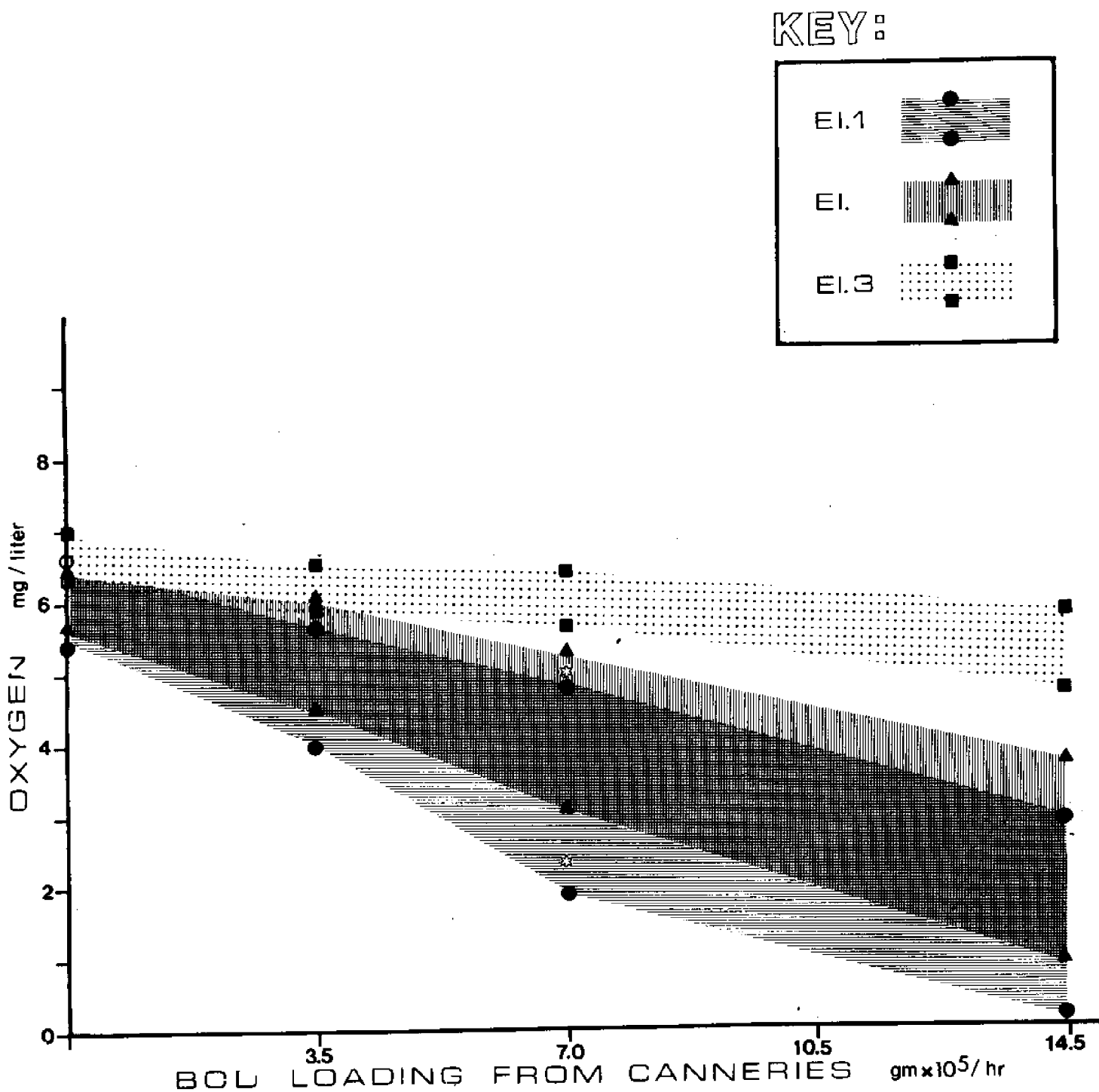


Figure C.2. The BOD loading from the canneries and TITP are dominant features in the oxygen budget. Note the slight increase in the oxygen level in element 1 when TITP loading is removed(*).

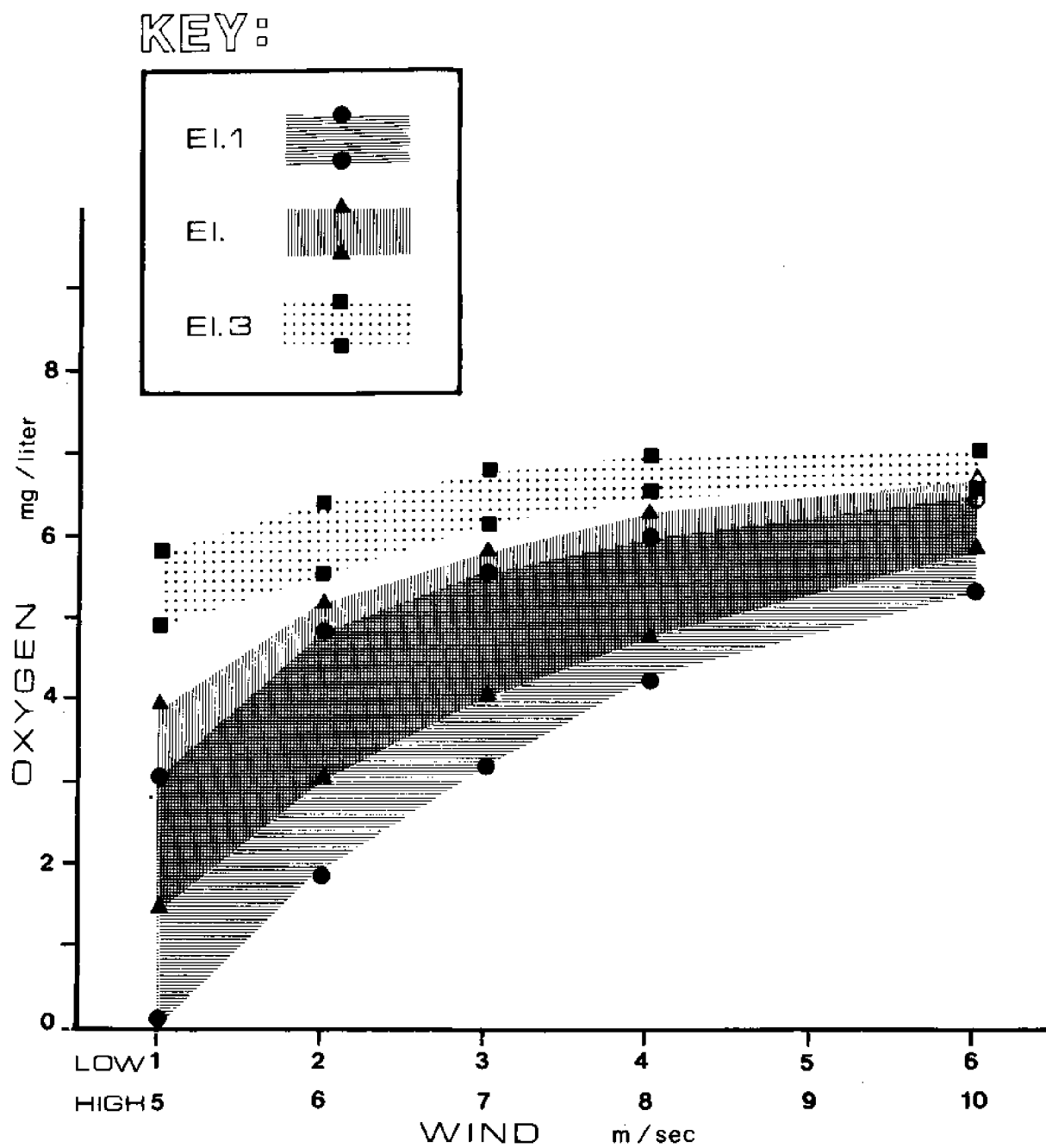


Figure C.3. Increasing wind speed (with a constant diurnal range) draws the oxygen towards saturation. This trend is most obvious for element 1.

KEY:

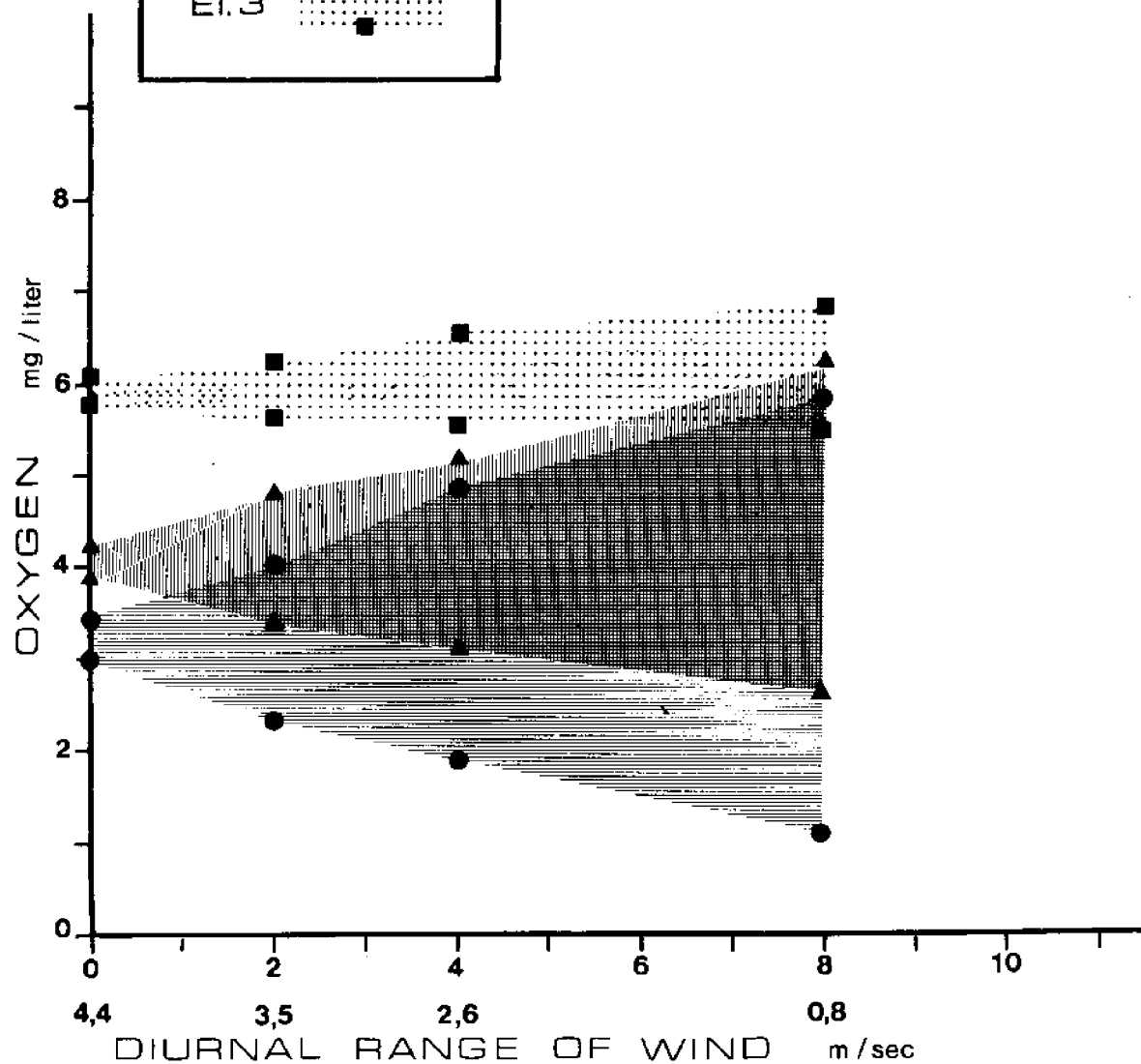
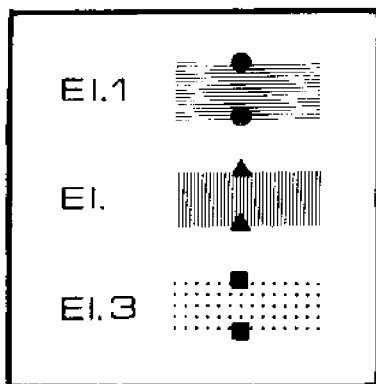


Figure C.4. Increasing diurnal range for the wind (constant average) results in an increased diurnal range in oxygen, particularly in element 1.

KEY:

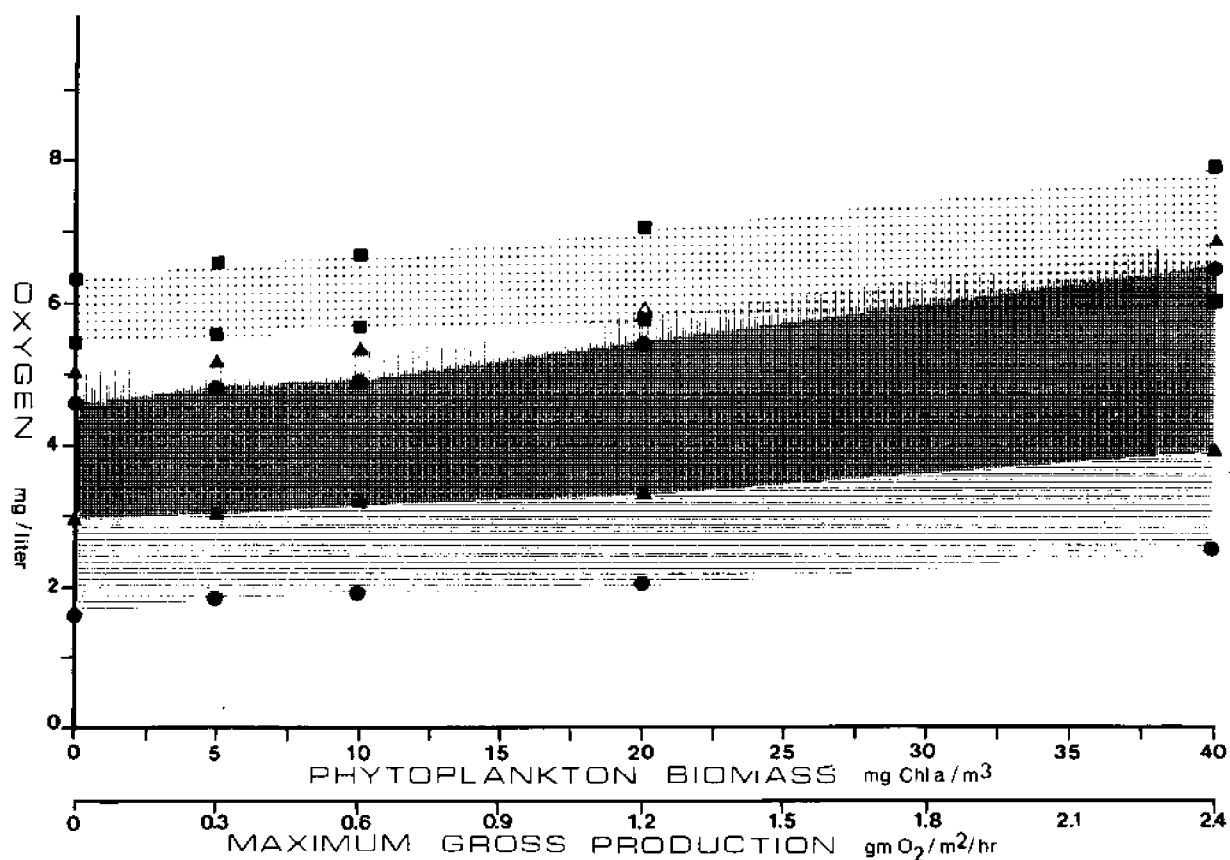
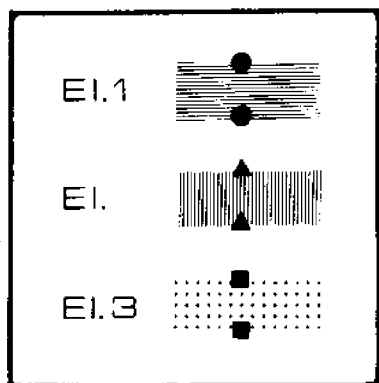


Figure C.5. Increasing phytoplankton biomass and production is reflected by slightly increased oxygen levels and greater diel range in all elements. It should be noted that in the harbor Chlorophyll a values rarely exceed 20 mg/m³.

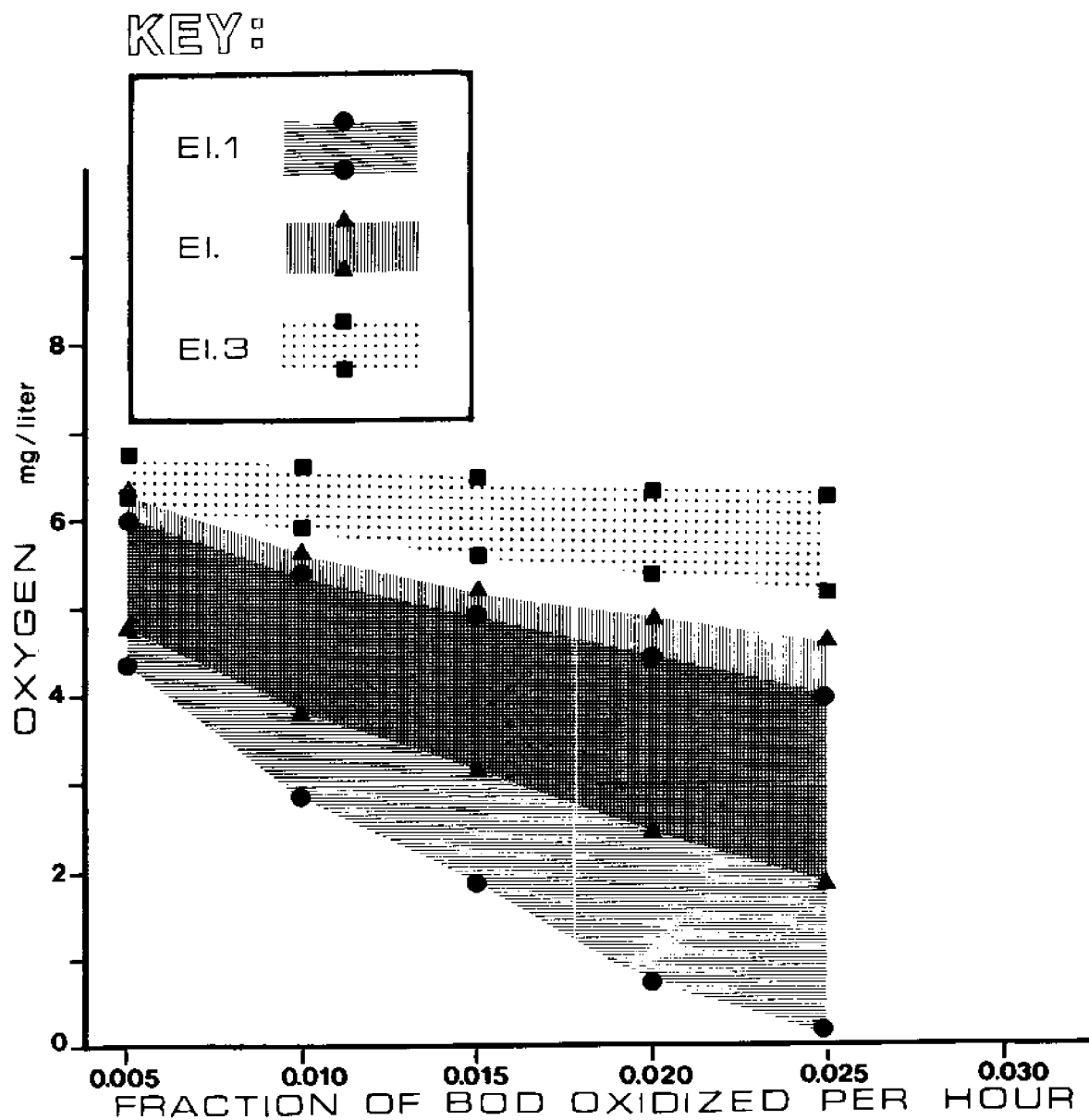


Figure C.6. The rate at which the BOD is oxidized is one of the most important factors in determining the dissolved oxygen level. Large variability in the results for determining this rate (Table A.1) add appreciably to imprecision in the standard run.

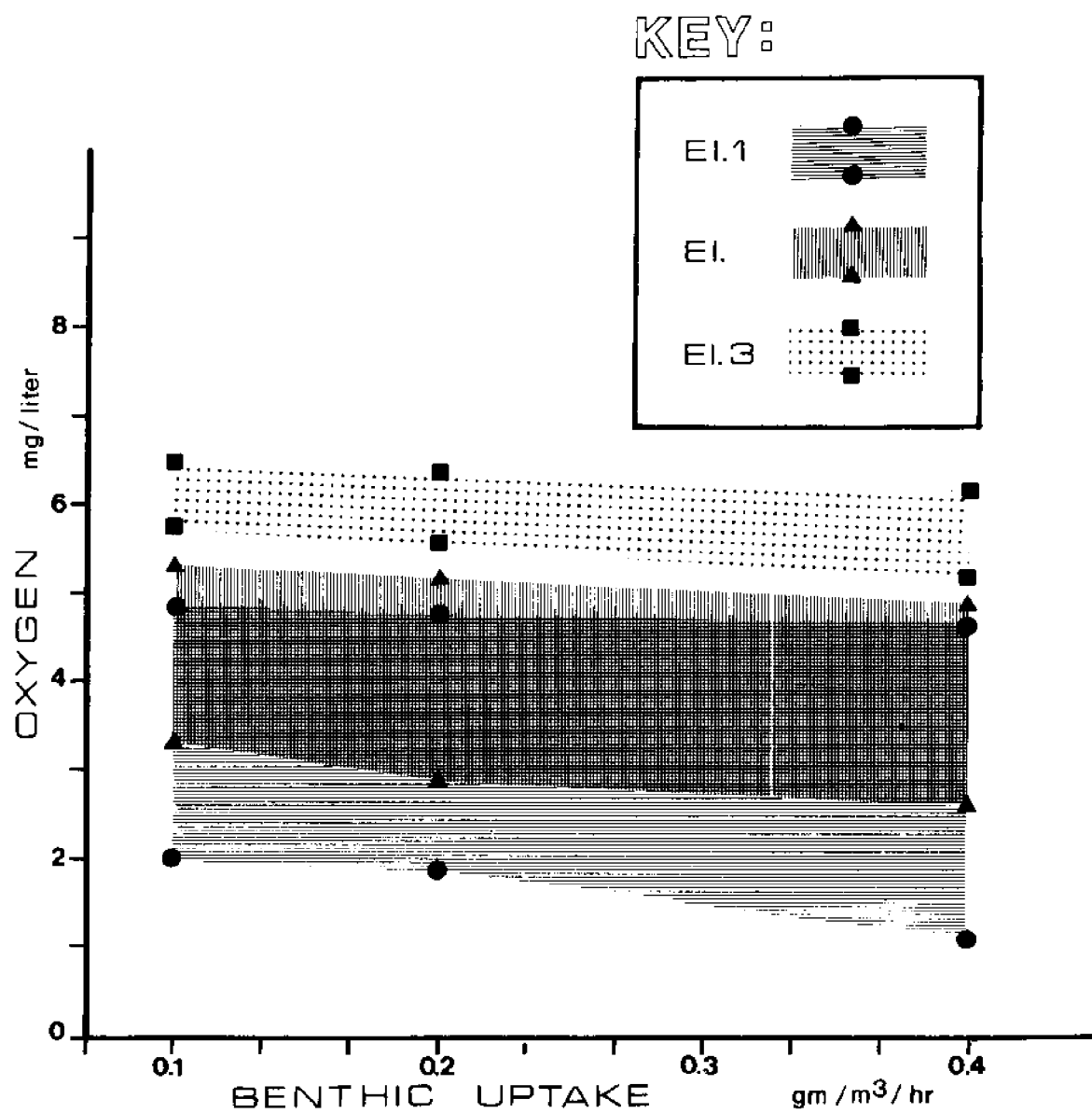


Figure C.7. The model seems to be fairly insensitive to a wide range of values for rate of benthic uptake.

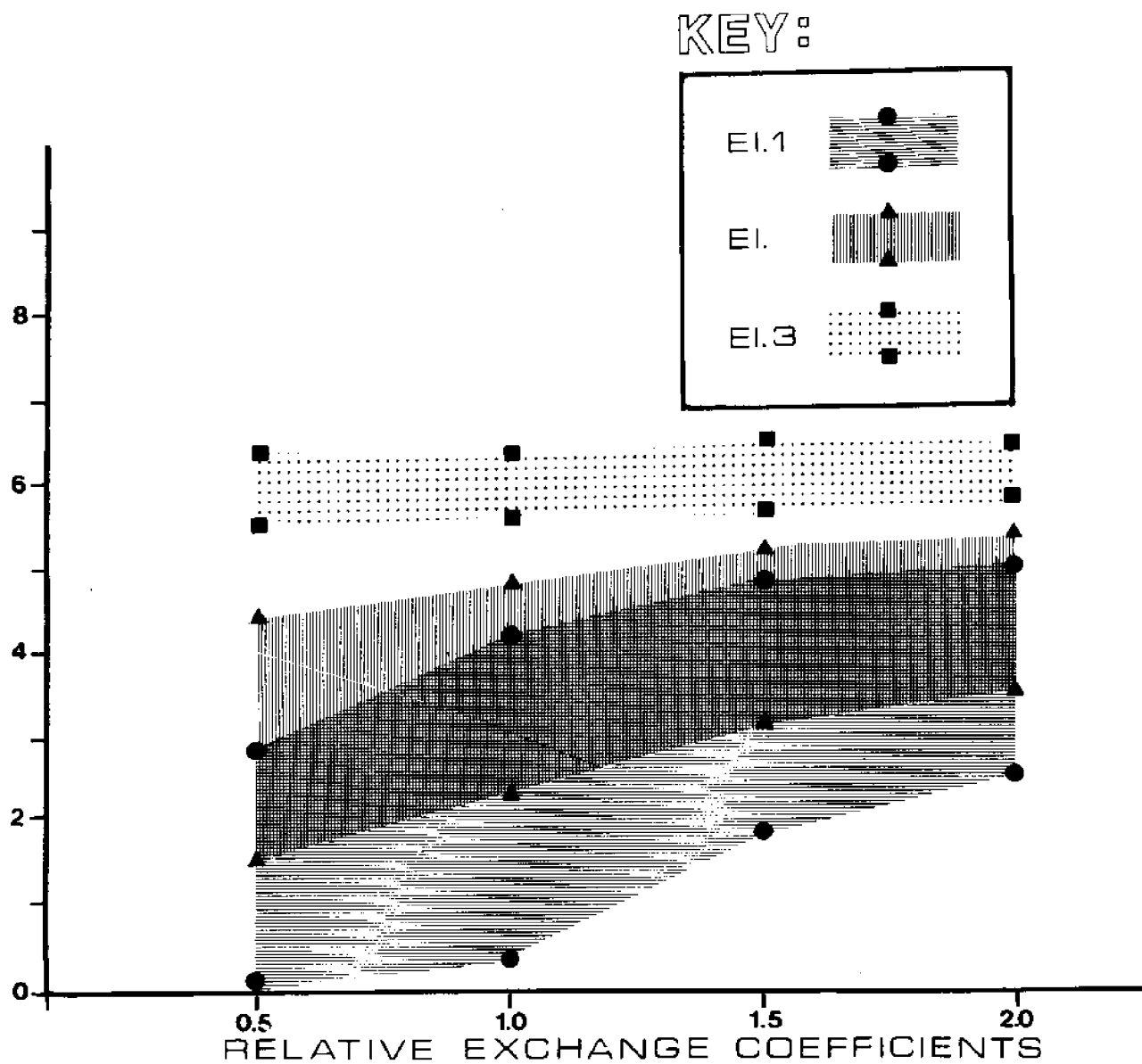


Figure C.8. Advective mixing is of moderate importance to the oxygen concentration, and most critical in the waters of element 1 closest to the outfalls.

MICROCOSM ENRICHMENT STUDIES OF TUNA CANNERY WASTE

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ABSTRACT. In 1977 tuna canneries in the Los Angeles-Long Beach Harbor converted from discharging raw waste to using a secondary sewage treatment (TITP) to treat the effluents before discharging them into the harbor. The consequences of this alteration of discharges on the microplankton were studied in two enrichment experiments on natural populations of coastal microplankton. It was found that high concentrations of cannery waste caused a diatom and dinoflagellate community to be replaced by a flagellate (unidentified nanoflagellate) and ciliate (*Uronema* sp.) community. Organisms of the genus *Uronema* are known to be available to planktonic grazers, and so may play a role in the plankton food web. Simulated secondary treated waste produced different effects depending on the major inorganic product formed. Nitrate stimulated, but ammonia inhibited, the growth of diatoms and dinoflagellates. Results indicated that these effects would be mostly local in extent.

ACKNOWLEDGMENTS. This research was supported by a Sea Grant Traineeship from the USC Sea Grant Program. I would also like to express my gratitude to the Harbors Environmental Projects and their technicians, notably Frank Edmands and Dan Dabelstein, for help with the field sampling; to Dr. B.C. Abbott for his counsel and review of this manuscript; and especially to Roseanne Ruse for her indispensable technical assistance.

INTRODUCTION

In recent years ecologists have begun to realize that human activities have subtle, but often profound influences on natural ecosystems. This is just now being recognized as regards the biota of the Los Angeles-Long Beach Harbor. As yet, very little is known about the ways in which human beings affect coastal marine communities. Despite this ignorance important changes in the harbor and effluents into it are being contemplated and made. One such change, which took place in the fall of 1977, was the rerouting of tuna cannery wastes through the Terminal Island Treatment Plant (TITP), which provides primary and secondary sewage treatment to these wastes. Cannery wastes, which for years have been discharged directly into the harbor, are now being modified before being returned to the waters of the harbor. The Allan Hancock Foundation has been following this change closely, using many approaches, to determine what effects it is having and will have upon harbor organisms (Soule and Oguri, 1976). This study is a part of that effort.

The aim of this investigation was to determine the effects cannery waste treatment was having or would have on the microplankton of the harbor, since it is this group of floating organisms that forms the base of the pelagic food web. Contained in the goal were two questions: (1) What effects did raw cannery waste have upon harbor microplankton? (2) What effects did (or would) TITP-treated cannery waste have upon harbor microplankton? Included in the microplankton community were microzooplankton as well as phytoplankton, and primarily excluded were zooplankton longer than 100 μ m.

The most straightforward approach to investigating the effects of any treatment on a natural group of organisms is to experiment with natural communities. Any retreat from this misrepresents the complexity and synergism of the natural ecosystem. Ideally, the natural system would be sampled extensively before treatment, during treatment, and afterward, while the same was done to an identical system which did not undergo treatment. Further, this experiment should be repeated for a variety of seasonal and other environmental conditions. Such a study is practically impossible, so at least one step must be taken toward artificiality. Edmondson and Edmondson (1947) and Edmondson (1955) were the first to explore the capture of sea water together with its inhabiting organisms (i.e., microcosms) in order to study natural productivity. More recently and successfully, McAllister *et al.* (1961), Parsons *et al.* (1977) and others have used large plastic bags, further improving the experiment's proximity to nature. The large volumes insure that larger, rarer, and more elusive organisms in higher trophic levels are included, and that wall effects are minimized. Thus, natural processes could be reliably inferred from these microcosm studies.

On a small scale, that was the approach used in this study. By using small volumes, applicability of the findings was limited somewhat, since

wall effects and trophic interactions in the experiments were almost certainly artificial. Nevertheless, this method can determine what influences are present with food web interactions largely absent. When this information is coupled with data concerning food web relationships, it will be possible to assess reliably the impact of events such as the above on the plankton community of the harbor, and perhaps other communities as well.

MATERIALS AND METHODS

The study consisted of two separate experiments using the same procedures. First, a seawater sample was collected at mid-morning in a 20 l. plastic carboy from a depth of 3m at Harbors Environmental Projects sampling station A1, outside the breakwater of the harbor, using a hand pump and flexible hose system designed for gentle collection of planktonic organisms. The first experiment began on September 20, 1977, and the second on December 7. The sea water was transported to the laboratory, a journey requiring approximately one hour. In the laboratory the carboy was shaken vigorously to distribute the contents evenly, and three 1 ml samples were removed with a pipette and fixed with Lugol's Iodine Fixative (Vollenweider, 1969). These sets of samples taken before the experiment began were referred to as "initial controls", whose mean composition was considered to be an additional experimental control.

Twelve more aliquots of sea water were removed from the carboy, which was shaken before each removal. These aliquots were placed into twelve 250 ml Erlenmeyer flasks and enriched with raw cannery waste, filtered cannery waste, a "simulated TITP" treatment, or left as controls. Each flask contained a final volume of 100 mls of solution. The flasks were placed on a rotary shaker and shaken at ca. 60 rpm at 18 C under continuous 5,000 lux fluorescent illumination for 72 hrs. After this incubation period, chosen to permit substantial phytoplankton growth without overgrowth and decay, each flask was shaken vigorously to distribute the contents evenly, and a 1 ml sample was pipetted out and fixed as above.

For counting, each 1 ml sample was washed into a settling chamber and allowed to settle overnight (Lund *et al.*, 1958). The entire sample was counted at 125X, then 5 random fields were examined at 312.5X for nanoplankton. Identifications were made according to the following primary authorities: diatoms-Cupp (1950), dinoflagellates-Schiller (1933, 1937), ciliates-Kahl (1935), miscellaneous flagellates-Fritsch (1935). Species counts were expressed as carbon, using cell volumes reported by Smayda (1965) and Strickland (1970), and conversion equations determined by Strathmann (1967).

Raw cannery waste was obtained the same day from inside the Starkist Tuna Cannery. It was immediately transported to the laboratory. It consisted of a foul-smelling, translucent, brown-gray liquid with flocculent

solids suspended in it. Left alone, these solids settled considerably. Since such settling might also occur in the harbor despite water movement, raw waste and waste filtered through a 0.2 μ m Nucleopore membrane filter to remove all particles were used. In addition to simulating a situation possibly occurring in the field, this would also indicate whether the major effects of cannery waste were caused by the solid or dissolved elements.

The third treatment was a simulation of the conditions which might occur with all cannery waste being treated by the TITP. In theory, secondary sewage treatment uses bacteria to oxidize organic wastes to inorganic form (Officer and Ryther, 1977). Of particular importance for phytoplankton are the nitrogen compounds. Organic nitrogen, in the form of proteins and amino acids and their immediate breakdown products, is converted to inorganic forms such as ammonia, nitrite and nitrate. It is not known how efficient TITP treatment is, or how thoroughly substances are oxidized. However, for the purposes of this study, a "best case" approach was adopted. That is, all the nitrogen entering the plant was assumed to be discharged in inorganic form, with none retained in the plant or lost elsewhere. It was also necessary to choose the form of inorganic nitrogen used in the experiment. In order to cover the spectrum of compounds possible, the first experiment assumed that all nitrogen was discharged as nitrate, and the second assumed that all was in the form of ammonia. These were crude assumptions, but refinement of them is possible only with reliable data on the actual performance of the TITP.

Levels of raw waste, filtered waste, and simulated TITP treatment (e.g., inorganic enrichment) were chosen to correspond to levels actually found in the harbor. Measurements of the parameters shown in Table 1 made near the cannery outfalls while waste was being discharged showed that dilution of cannery waste occurred quite rapidly (G. Brewer, unpublished data). In fact, the range of cannery waste concentrations in the harbor can be covered by considering three orders of magnitude: 0.1%, 1% and 10%. On that basis, these three concentrations were used. For simulated TITP treatment, levels of phosphorus and nitrogen in cannery waste were determined, and equal concentrations of inorganic phosphate and nitrate (in Experiment 1) or ammonia (in Experiment 2) were used. Table 2 summarizes the treatments and levels used in the two experiments.

There was one additional change in method between Experiments 1 and 2. Since it has long been known that silica can leach out of glass containers, thereby favoring the growth of diatoms over what might otherwise occur, the glass flasks of Experiment 1 were replaced by polycarbonate containers in Experiment 2. This eliminated the possibility that the flasks would have an effect on the outcome of Experiment 2, allowing these results to be compared with those in Experiment 1 for evidence of glass effects there.

Since this was a preliminary study, replication was held to a minimum. For each experiment three experimental controls were run, but the treatments

were not replicated. Thus it was not possible to compare treatments directly with one another with measurable statistical confidence. However, since there were three experimental controls and an "initial control" mean (which reflected the initial composition of the microplankton), a measure of the dispersion of untreated (control) communities was available. This was used to perform t-tests of the significances of differences between treatments and controls (Sokal and Rohlf, 1969). Because the variance of the controls was dependent upon the sample mean (Fig. 1), data were $\log(x+1)$ transformed before being tested.

An added measure of the reproducibility of results was present due to the duplication, in most respects, of Experiment 1 by Experiment 2. Of course, because of the differences in the initial communities, results from the two experiments could not be justifiably pooled to obtain additional statistical precision. Nevertheless, results occurring in both experiments were clearly more significant than those occurring in only one.

Experiment 2 began with a very small plankton community. This, together with the large cell sizes of some of the species present, produced an extraordinarily high variance in the controls. In view of this and the few data from which the variance was calculated, the concept of statistical significance was extended somewhat. It was hypothesized that the measurement of control variance had been made using five samples, not four, as was actually the case. This brought out results which were not significant on the basis of the few data available, but would have been significant if the data had been only slightly more complete. This did not purport to be a rigorous test of significance, but rather a device for sorting out probably significant trends for support of other, independently significant results. It was a way of recognizing the insufficiency of certain data for providing conclusive answers, while indicating promising hypotheses for further testing.

RESULTS AND DISCUSSION

The results of Experiments 1 and 2 are presented fully in Appendix Tables 1-6. Table 3 illustrates the composition of the natural microplankton samples used in the two experiments of this study. The sample used in Experiment 1 differed considerably from the one used in Experiment 2. First, the total biomass was an order of magnitude higher in the first experiment. In addition, the species distributions of the two were different. Experiment 1 was dominated by the two red tide dinoflagellates, *Cochlodinium catenatum* Okamura and *Gonyaulax polyedra* Stein, while Experiment 2 lacked *Cochlodinium* entirely. The proportions of the other species were also quite different in the two experiments. However, both communities were dominated overwhelmingly by diatoms and especially dinoflagellates. This is common in the fall plankton of the coast of southern California (Allen, 1941; Strickland, 1970). So, despite the differences in details of species composition, both experimental communities were well

within normal limits for plankton in this area.

As Figures 2 and 3 show, the major phytoplankters (diatoms and dinoflagellates) were strongly affected by cannery waste. These pooled data show that both raw and filtered cannery waste at 10% concentrations reduced the biomass significantly in both experiments. In examining dinoflagellates alone, this same depression is evident (Figure 4). Cannery waste significantly diminished biomass in 10% raw and filtered waste and in 1% raw waste in Experiment 1. Because of the small amount of plankton and the large sizes of the dominant dinoflagellates, the data for Experiment 2 did not achieve significance, but the same trend was shown (Figure 5). Diatoms also decreased also, as shown in Figures 6 and 7, but these changes, too, were insignificant. Nevertheless, high levels of cannery waste reduced the standing stock of the major southern California phytoplankton species.

At the same time, other members of the microplankton were favored. Small flagellates and ciliates, whose pooled biomass is represented in Figures 8 and 9, reached tremendous numbers under the influence of cannery waste. In Experiment 1 raw waste at all concentrations produced a significant increase, and in Experiment 2 both raw and filtered waste produced significant increases at 10% concentrations. This effect was also seen in flagellates alone (Figures 10 and 11), where in all cases except one cannery waste produced a significant increase in biomass. Figures 12 and 13, showing ciliates alone, further illustrate this effect, though these results were not as consistent as those of small flagellates. Still, these results show that high concentrations of cannery waste promote the growth of flagellates (especially an unidentified nanoflagellate species) and ciliates (especially a species of *Uronema* Dujardin).

In short, cannery waste produced a dramatic change in the composition of the microplankton. Under its influence a normal diatom-dinoflagellate community changed to a flagellate-ciliate community. This is summarized in Figures 14-17. Since the trends of both experiments reinforce one another, there is no evidence that the differences in containers affected the results.

Although this study was not designed to determine the mechanisms involved in these changes, several possibilities exist and on the basis of these findings, warrant investigation. The decrease in phytoplankton may be due simply to poisoning of algae by toxic elements in cannery waste. Cannery waste contains a great deal of organic carbon, organic nitrogen, and ammonia compounds (Table 1), which could have toxic effects on algae (Kinne, 1976). Alternatively, cannery waste may not be toxic but merely confer a competitive advantage on the nanoflagellate species, especially if the nanoflagellate is capable of heterotrophy (Ryther, 1954). Because of the high organic content, cannery waste also promoted the growth of bacteria, and it is possible that among them were algal pathogens. Of course, these hypotheses may all be true, since these mechanisms are not mutually exclusive.

The cause of dominance by ciliates in cannery waste enrichment is an important problem, since it may affect the food web. *Uronema* was probably feeding upon the bacteria that thrive on cannery waste, since many ciliates are presumed- and some, including *Uronema* species, have been shown- to be bacterivores (Hamilton and Preslan, 1970; Drake and Tsuchiya, 1976). Alternatively or in addition, they may be feeding directly upon cannery waste, or some component of it. They may be feeding partly on the greatly increased concentrations of oil and grease (Table 1), since certain fats are known to promote growth in some ciliates (Holz *et al.*, 1961). Planktonic copepods can feed on *Uronema* (Bert *et al.*, 1977), so ciliate population dynamics may affect the local food web significantly. In the sense that energy is lost to an intermediate trophic level, ciliates feeding on bacteria which feed on cannery waste is a much less efficient, and therefore possibly less productive, energy pathway than ciliates feeding directly on cannery waste. On this basis, the cannery waste-bacteria-ciliate-copepod relationships are important aspects for further quantitative study.

Though it was not possible to test statistically the significances of differences between experimental treatments, the results do provide some evidence about the importance of dissolved substances in affecting microplankton. The effects of raw and dissolved cannery waste were very similar, though raw waste usually produced greater stocks of ciliates and flagellates (Figures 8-13). This strongly suggests that many of the effects of cannery waste were caused by dissolved substances.

Figures 18 and 19 show the total biomass of microplankton, all components included, as related to enrichment for both experiments. No significant change was observed, but with one more degree of freedom in Experiment 2, the biomass in 10% raw waste would have been significantly greater than in the controls. There was a clear trend toward increased biomass with greater enrichment, but as Figure 18 shows, this was not universal.

The results of TITP simulations are presented in Figures 20 and 21. In attempting to cover the range of effects of TITP influence using nitrate and ammonia, in effect two completely different experiments were created. In the first, enrichment produced a significant increase in diatoms and dinoflagellates (though individually the increases in these components were not statistically significant) but no consistent effect on ciliates and flagellates (Figure 10 notwithstanding). The second experiment, on the other hand, produced different results. Figures 3 and 5 show an increase in biomass at the highest level of enrichment. However, Appendix Table 6 shows that this increase was due only to the chance inclusion of one cell of the large dinoflagellate *Protoperidinium crassipes* (Kofoid) Balech, having a carbon weight of 134.3 ng. With this improbable event discarded, the results depicted in the figures are consistent (Figures 22 and 23). On that basis I believe that the TITP simulation in Experiment 2 produced a decrease in the biomass of

diatoms and dinoflagellates, though not to the point of statistical significance.

Most photosynthetic diatoms and dinoflagellates are known to be able to use both nitrate and ammonia as nitrogen sources. In most cases ammonia is preferred (Kinne, 1976). Therefore, the explanation that the decrease in Experiment 2 was due to an inability of any algae to use ammonia must be rejected. More likely, the level of ammonia was detrimental either by lowering the pH of the medium to lethal levels or by being directly toxic. Concentrations greater than 0.5 mg.-at/l. have been found to be toxic to algae (Admiraal, 1977; Kinne, 1976) and Experiment 2 contained up to 3.0 mg.-at/l.

In short, TITP treatment, if it produced a high proportion of well oxidized nitrogenous material (i.e., nitrates), would tend to increase the standing stock of phytoplankton, while less oxidized components (i.e., ammonia) in high enough concentrations, would tend to decrease it.

Up to this point I have been dealing on a largely theoretical level, even with experimental results. Having expressed what appear to be the effects the two alternative forms of cannery waste might produce, I must point out those mitigating factors already apparent. To begin with, small volume microcosms are not natural systems, so many of the cybernetic systems found in nature must be absent in such experiments. In nature, these systems would alter the effects produced in the laboratory. One such system is the food web. Because these were short experiments and large predators were not present in natural quantities, there is no way of knowing how quickly the natural ecosystem would dampen changes in biomass. It is quite possible that production rates at all levels of the food web could increase, yet the standing stock remain the same. On the other hand, it is not known what the planktonic food web of the harbor is like. If it involves much selectivity, then the effects of changes obtained in this study could even be magnified. That is, a change in the quality of the microplankton, e.g., from a diatom-dinoflagellate community to a ciliate-flagellate community, could drastically affect the grazers upon those organisms. Such a qualitative change in microzooplankton even without any change in total biomass could change the complexion of the local food web. If this is accompanied by a biomass change, even larger changes could result.

Perhaps the largest unknown is what the TITP actually does. There is great variability from sewage plant to sewage plant, and the TITP is still in the initial phases of operation on cannery waste. Still, it is certain not to convert 100% of the nitrogenous compounds and discharge every bit, as was assumed in this study. A more reasonable assessment would be that 50% of the nitrogen which enters the plant emerges into the harbor (Weinberger et al., 1966). Much of the difference is probably lost as gas.

So much is unknown about the effects of changes like the cannery waste shift that it is not merely scientific curiosity that argues for large

scale further study of the relative effects of raw versus treated wastes. As I have indicated, nothing short of profound investigation will permit ecologists to say with reasonable assurance what such human influence does. At the same time, recent history has shown clearly that such human activities can be dangerous if pursued in customary ignorance (Ryther, 1954).

CONCLUSIONS

1. Cannery waste, raw or filtered, stimulates the growth of flagellates (especially a species of nanoflagellate) and ciliates (especially a species of *Uronema*), while inhibiting the growth of planktonic diatoms and dinoflagellates.

2. TITP treatment may act either to stimulate or inhibit the growth of phytoplankton, depending upon the concentrations and identities of the nitrogenous products formed. If large amounts of ammonia are discharged, phytoplankton will be inhibited locally. If large amounts of nitrate are discharged, phytoplankton will be stimulated.

3. The effects of these discharges are local, since dilution occurs rapidly, obscuring effects in all but the highest concentrations.

4. Because of the change in the nature of the microplankton community associated with conversion from raw cannery waste discharge, until the nature of the harbor food web is better known no real assessment of the effects of this change can be made.

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Table 1. Comparison of Components of Cannery Waste and Sea Water.

| | Star-Kist Cannery Waste | Station A1 Sea Water |
|---|----------------------------|-------------------------|
| Oil and Grease ($\mu\text{g./l.}$) | 22,000 | 250 |
| Inorganic Carbon ($\mu\text{g-at/l.}$) | 1,670 | 333 |
| Organic Carbon ($\mu\text{g-at/l.}$) | 5,830 | 667 |
| Kjeldahl Nitrogen ($\mu\text{g-at/l.}$) | 2,705 | 15 |
| Ammonia ($\mu\text{g-at/l.}$) | 440 | 38.2 |
| Nitrite ($\mu\text{g-at/l.}$) | 3.13 | 0.76 |
| Nitrate ($\mu\text{g-at/l.}$) | 0.46 | 3.01 |
| Phosphate ($\mu\text{g-at/l.}$) | 36.7 | 1.50 |
| BOD (mg./l.) | 780 | 4.30 |

Table 2. Experimental Design and Treatments.

| <u>Controls</u> | <u>0.1% Concentration</u> | <u>1% Concentration</u> | <u>10% Concentration</u> |
|---------------------------------|---------------------------------|-------------------------------|--------------------------------|
| | 99.9 mls. Natural Population | 99 mls. Natural Population | 90 mls. Natural Population |
| | 0.1 ml. Artificial Sea Water | 1 ml. Artificial Sea Water | 10 mls. Artificial Sea Water |
| <u>Raw Cannery Waste</u> | 99.9 mls. Natural Population | 99 mls. Natural Population | 90 mls. Natural Population |
| | 0.1 ml. Raw Cannery Waste | 1 ml. Raw Cannery Waste | 10 mls. Raw Cannery Waste |
| <u>Filtered Cannery Waste</u> | 99.9 mls. Natural Population | 99 mls. Natural Population | 90 mls. Natural Population |
| | 0.1 ml. Filtered Cannery Waste | 1 ml. Filtered Cannery Waste | 10 mls. Filtered Cannery Waste |
| <u>Simulated TITP Treatment</u> | 99.9 mls. Natural Population | 99 mls. Natural Population | 90 mls. Natural Population |
| | 0.1 ml. Artificial Sea Water | 1 ml. Artificial Sea Water | 10 mls. Artificial Sea Water |
| | + 70 $\mu\text{g-at/l. P}^1$ | + 7 $\mu\text{g-at/l. P}^1$ | + 0.7 $\mu\text{g-at/l. P}^1$ |
| | + 3,000 $\mu\text{g-at/l. N}^2$ | + 300 $\mu\text{g-at/l. N}^2$ | + 30 $\mu\text{g-at/l. N}^2$ |

¹Added as $\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$.

²In Experiment 1, NO_3 added as NaNO_3 . In Experiment 2, NH_3 added as NH_4Cl .

Table 3. Composition of "Initial Control" Microplankton Communities (ng. C. ml.⁻¹).

| SPECIES | Experiment 1 | Experiment 2 |
|-------------------------------|--------------|--------------|
| DINOFLAGELLATES | | |
| <i>Cochlodinium catenatum</i> | 58.710 | 0 |
| <i>Gonyaulax polyedra</i> | 35.030 | 9.134 |
| <i>Ceratium</i> spp. | 5.707 | 0.971 |
| <i>Prorocentrum</i> spp. | 0.661 | 0 |
| <i>Protoperidinium</i> spp. | 4.870 | 1.423 |
| Other Dinoflagellates | 4.211 | 0.037 |
| Total Dinoflagellates | 109.189 | 11.565 |
| DIATOMS | | |
| <i>Leptocylindrus danicus</i> | 2.072 | 0 |
| <i>Asterionella japonica</i> | 0.129 | 0 |
| <i>Ditylum brightwellii</i> | 5.435 | 0 |
| <i>Hemicaulis</i> spp. | 0 | 0.360 |
| <i>Chaetoceros</i> spp. | 10.612 | 0.551 |
| <i>Nitzschia</i> spp. | 0.268 | 0.005 |
| Other Diatoms | 1.503 | 0.800 |
| Total Diatoms | 20.020 | 1.716 |
| Diatoms + Dinoflagellates | 129.209 | 13.281 |
| FLAGELLATES | | |
| Nanoflagellate sp. | 5.760 | 0 |
| Other Flagellates | 0.402 | 0.183 |
| Total Flagellates | 6.142 | 0.183 |
| CILIATES | | |
| <i>Uronema</i> sp. | 0 | 0 |
| Oligotrichida, unid. | 2.881 | 0.079 |
| Other Ciliates | 6.711 | 0 |
| Total Ciliates | 9.592 | 0.079 |
| Flagellates + Ciliates | 15.734 | 0.262 |
| Total Microplankton | 144.943 | 13.543 |

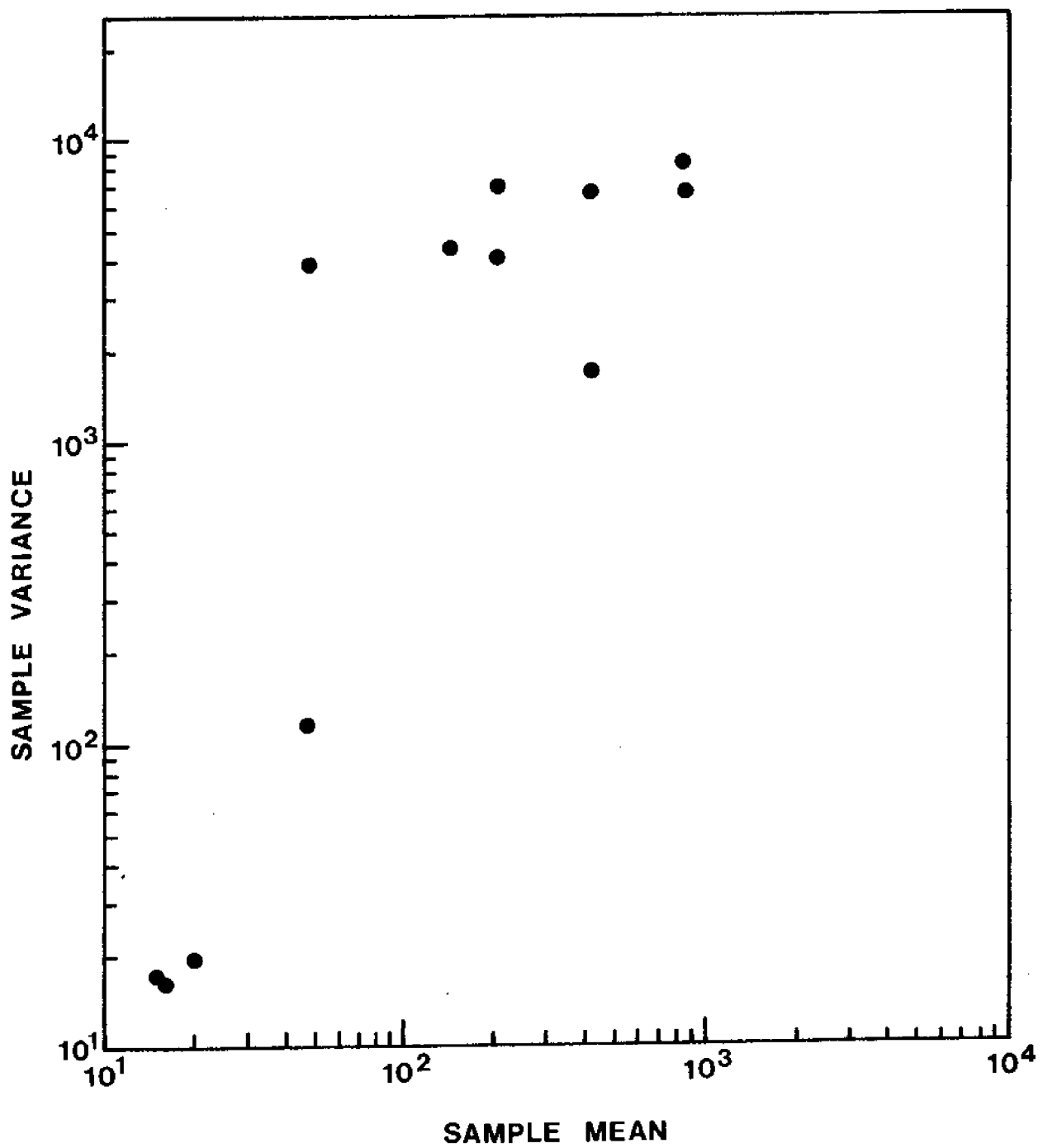


FIGURE 1. VARIANCE-MEAN RELATIONSHIP OF RAW DATA.

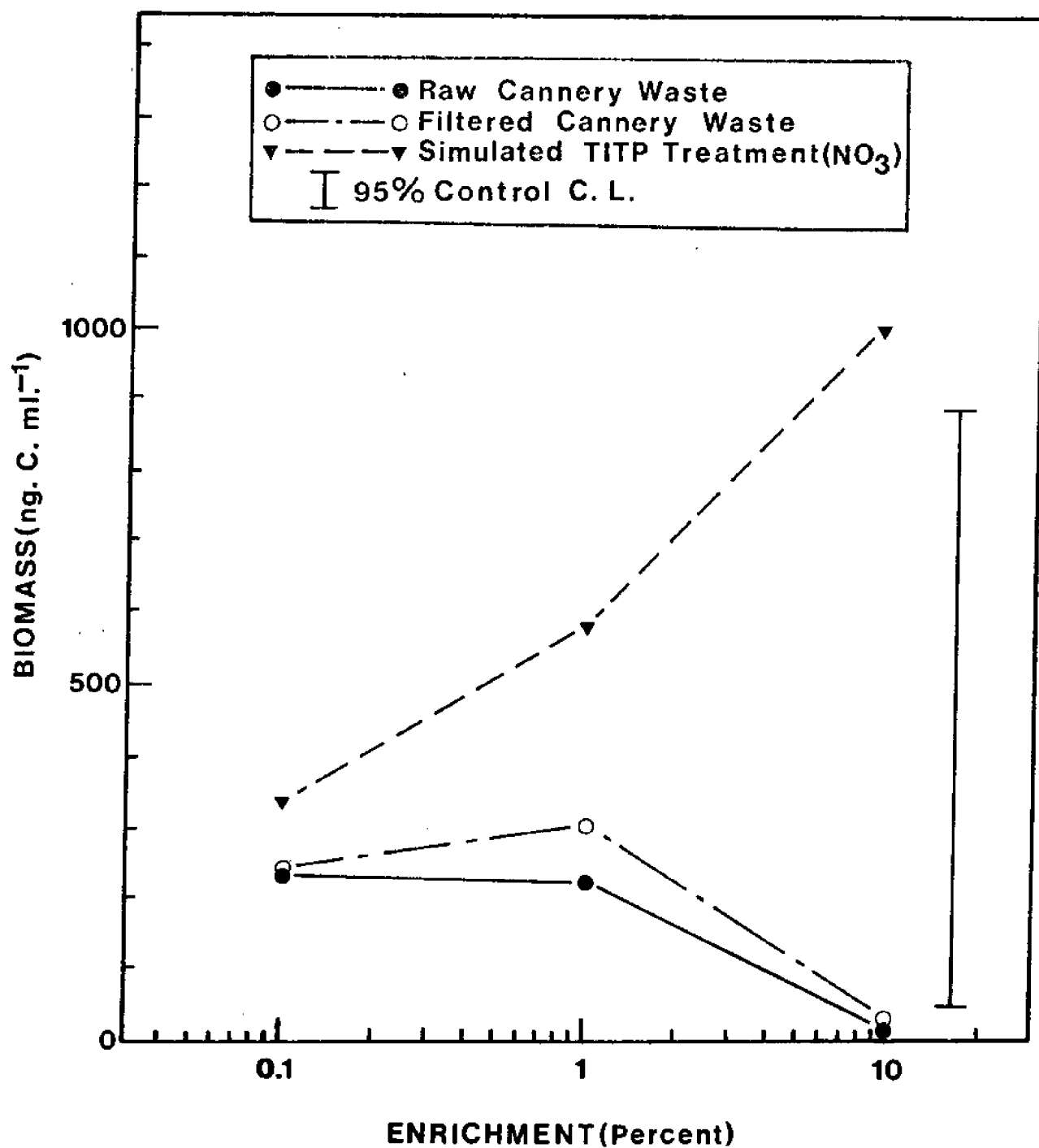


FIGURE 2. ENRICHMENT EFFECTS ON DIATOMS + DINOFLAGELLATES (EXPERIMENT 1).

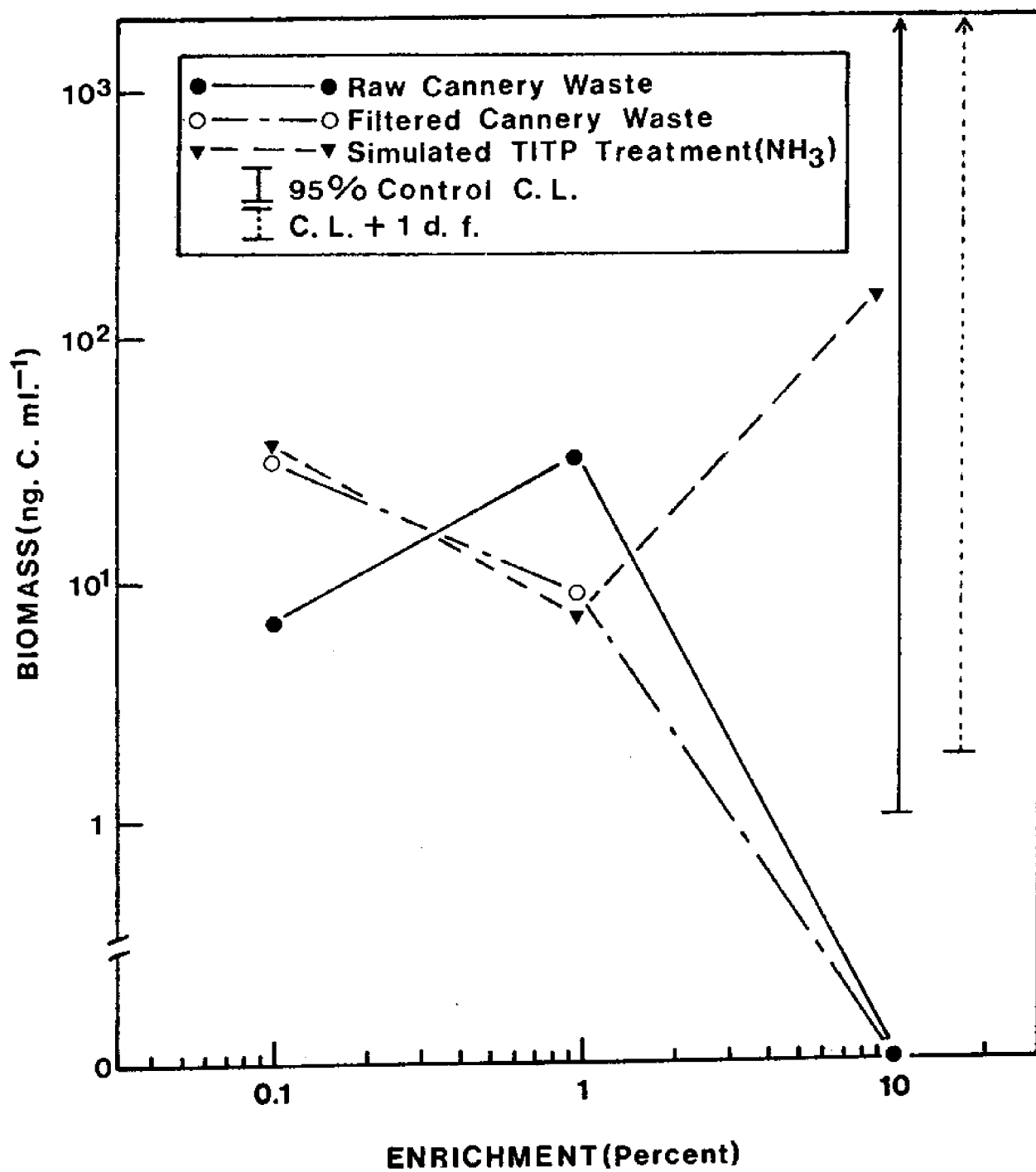


FIGURE 3. ENRICHMENT EFFECTS ON DIATOMS + DINOFLLAGELLATES (EXPERIMENT 2).

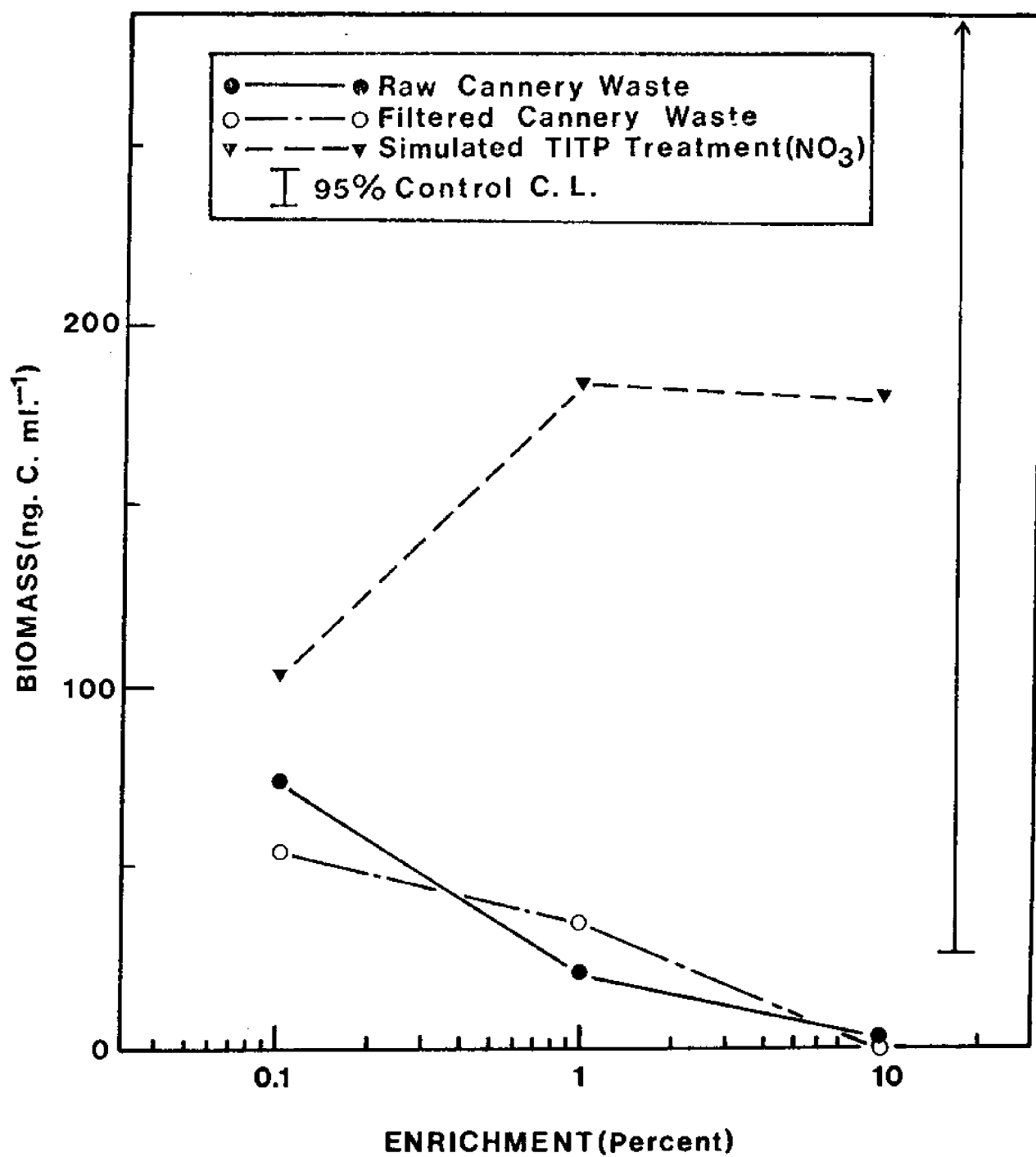


FIGURE 4. ENRICHMENT EFFECTS ON DINOFLAGELLATES (EXPERIMENT 1).

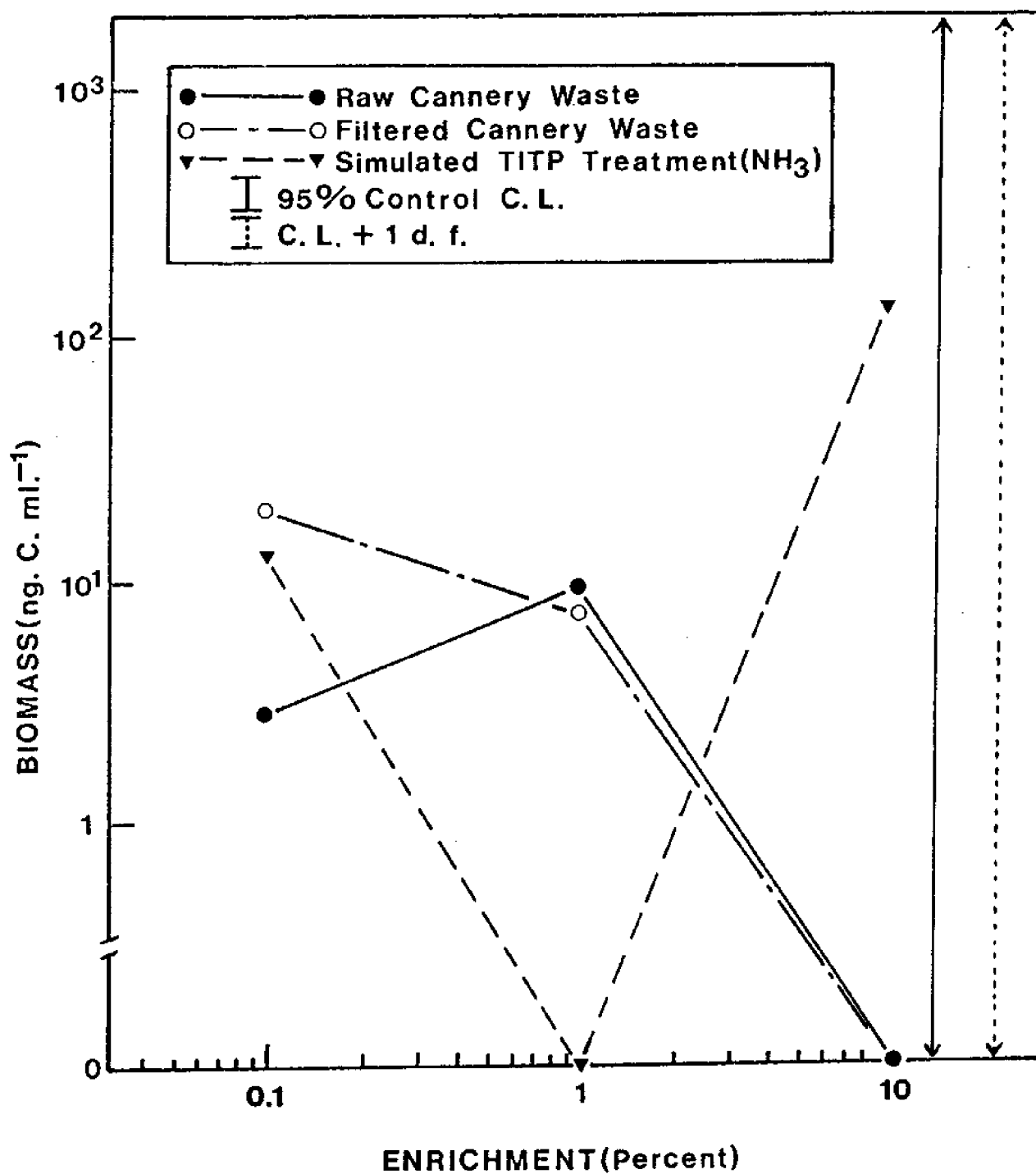


FIGURE 5. ENRICHMENT EFFECTS ON DINOFLAGELLATES (EXPERIMENT 2).

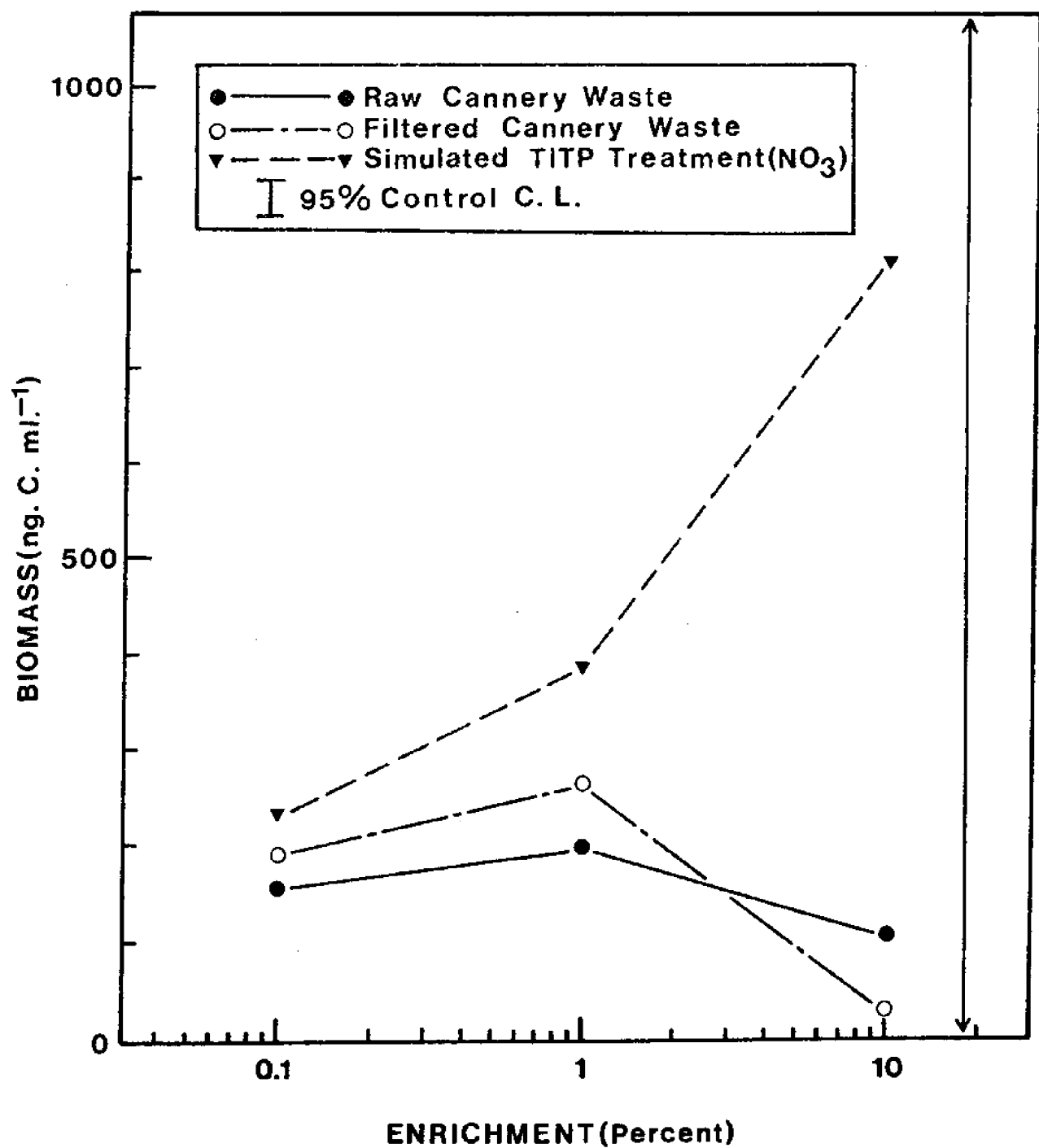


FIGURE 6. ENRICHMENT EFFECTS ON DIATOMS (EXPERIMENT 1).

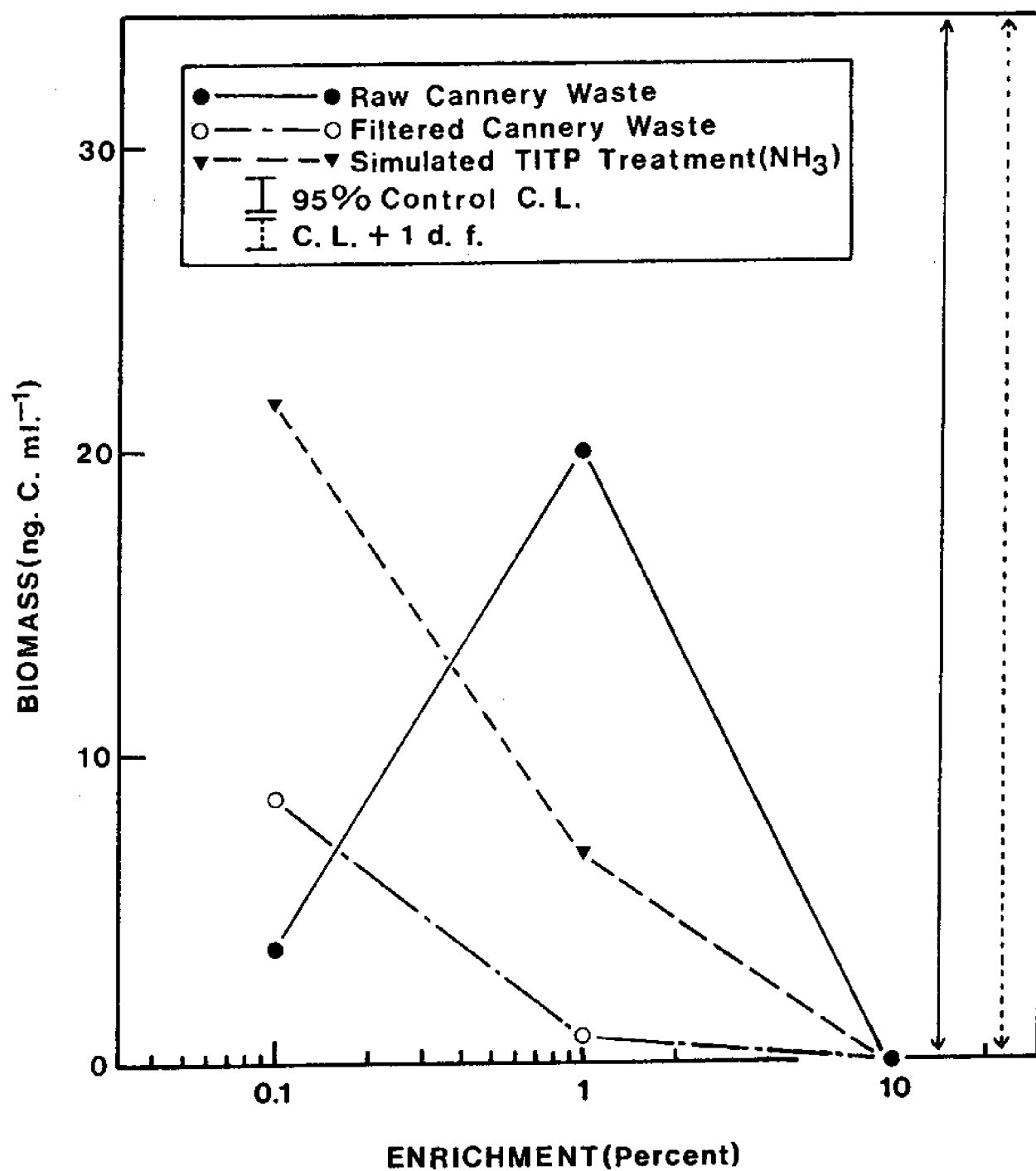


FIGURE 7. ENRICHMENT EFFECTS ON DIATOMS (EXPERIMENT 2).

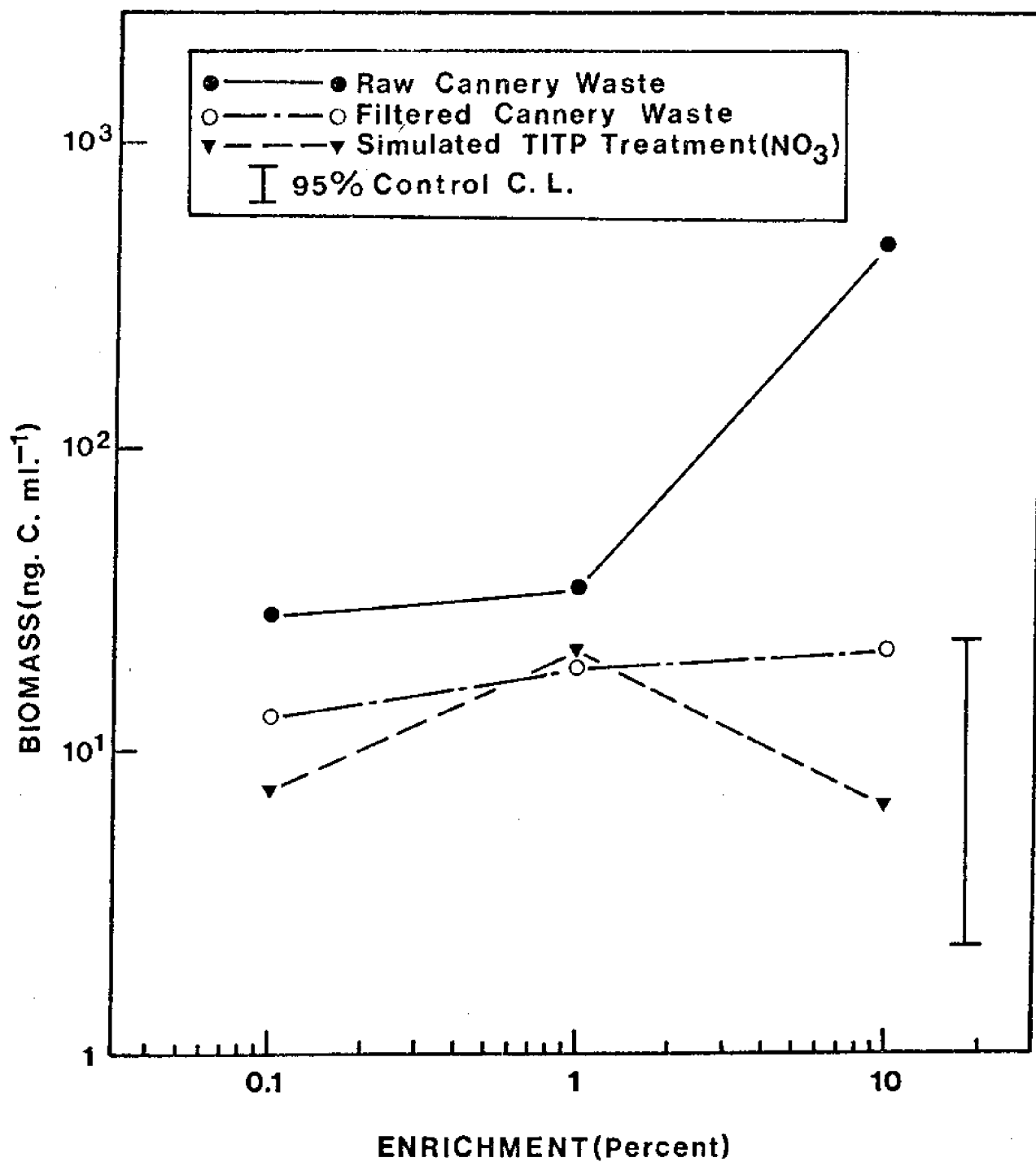


FIGURE 8. ENRICHMENT EFFECTS ON FLAGELLATES + CILIATES (EXPERIMENT 1).

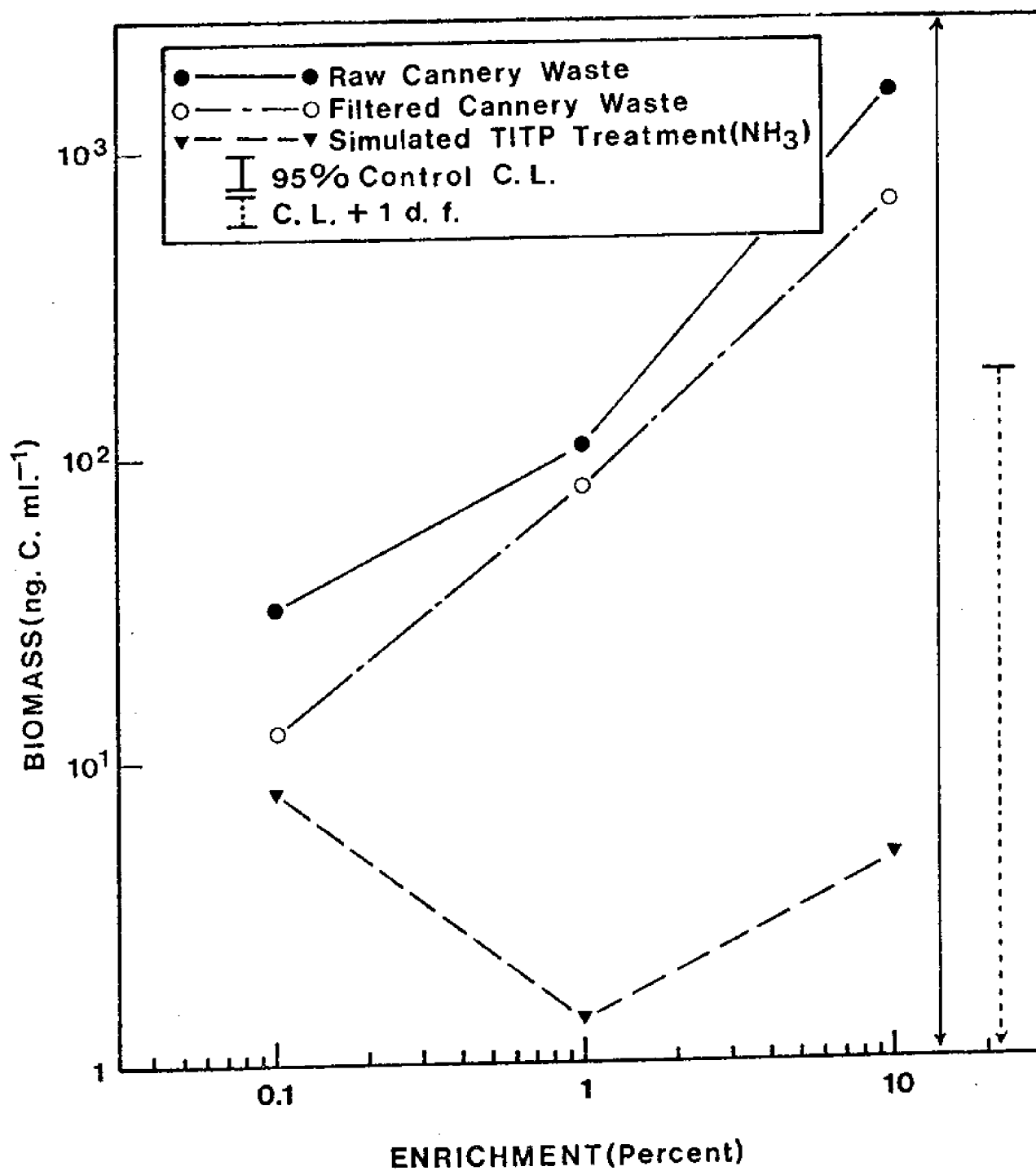


FIGURE 9. ENRICHMENT EFFECTS ON FLAGELLATES + CILIATES (EXPERIMENT 2).

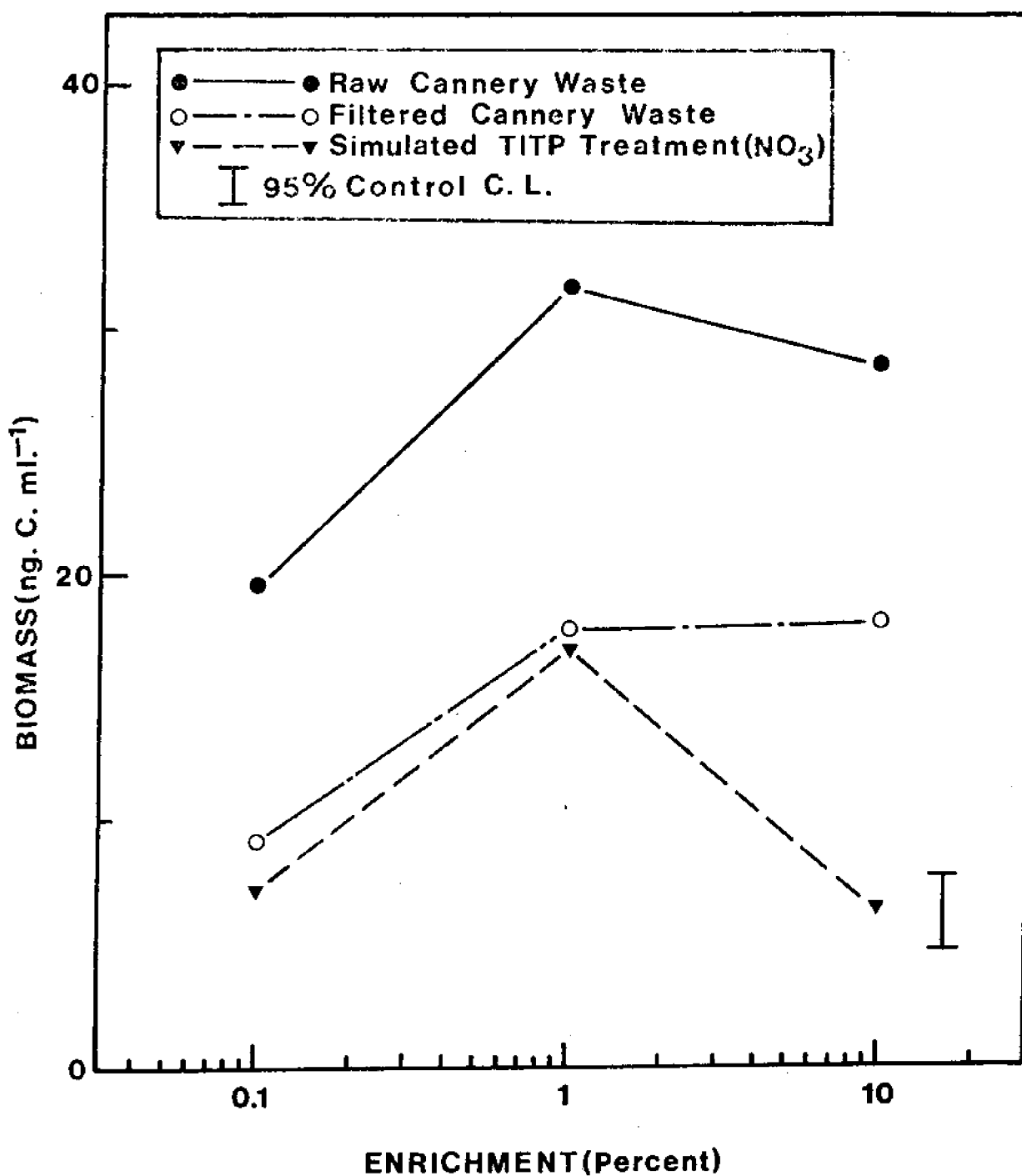


FIGURE 10. ENRICHMENT EFFECTS ON FLAGELLATES (EXPERIMENT 1).

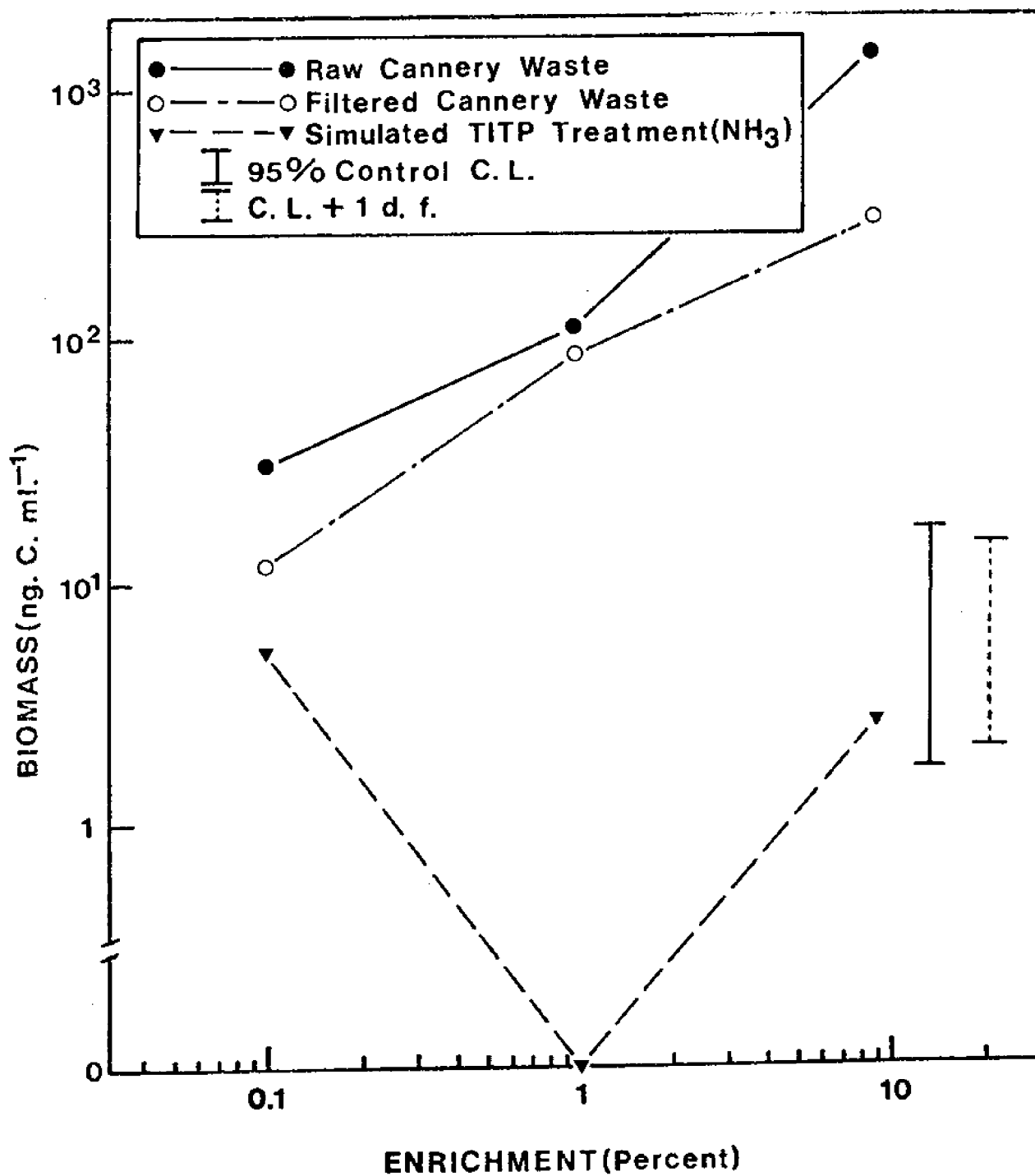


FIGURE 11. ENRICHMENT EFFECTS ON FLAGELLATES (EXPERIMENT 2).

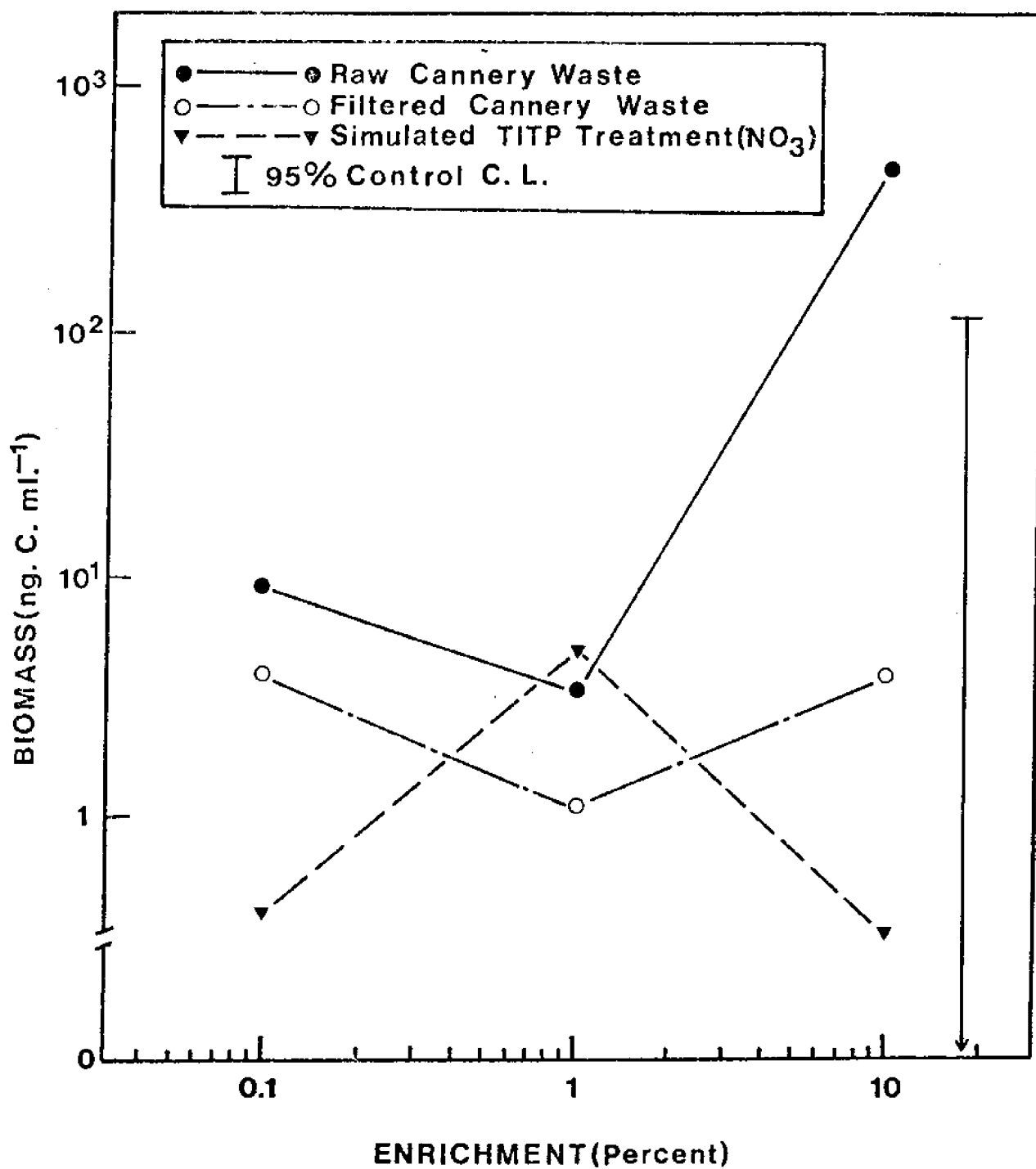


FIGURE 12. ENRICHMENT EFFECTS ON CILIATES (EXPERIMENT 1).

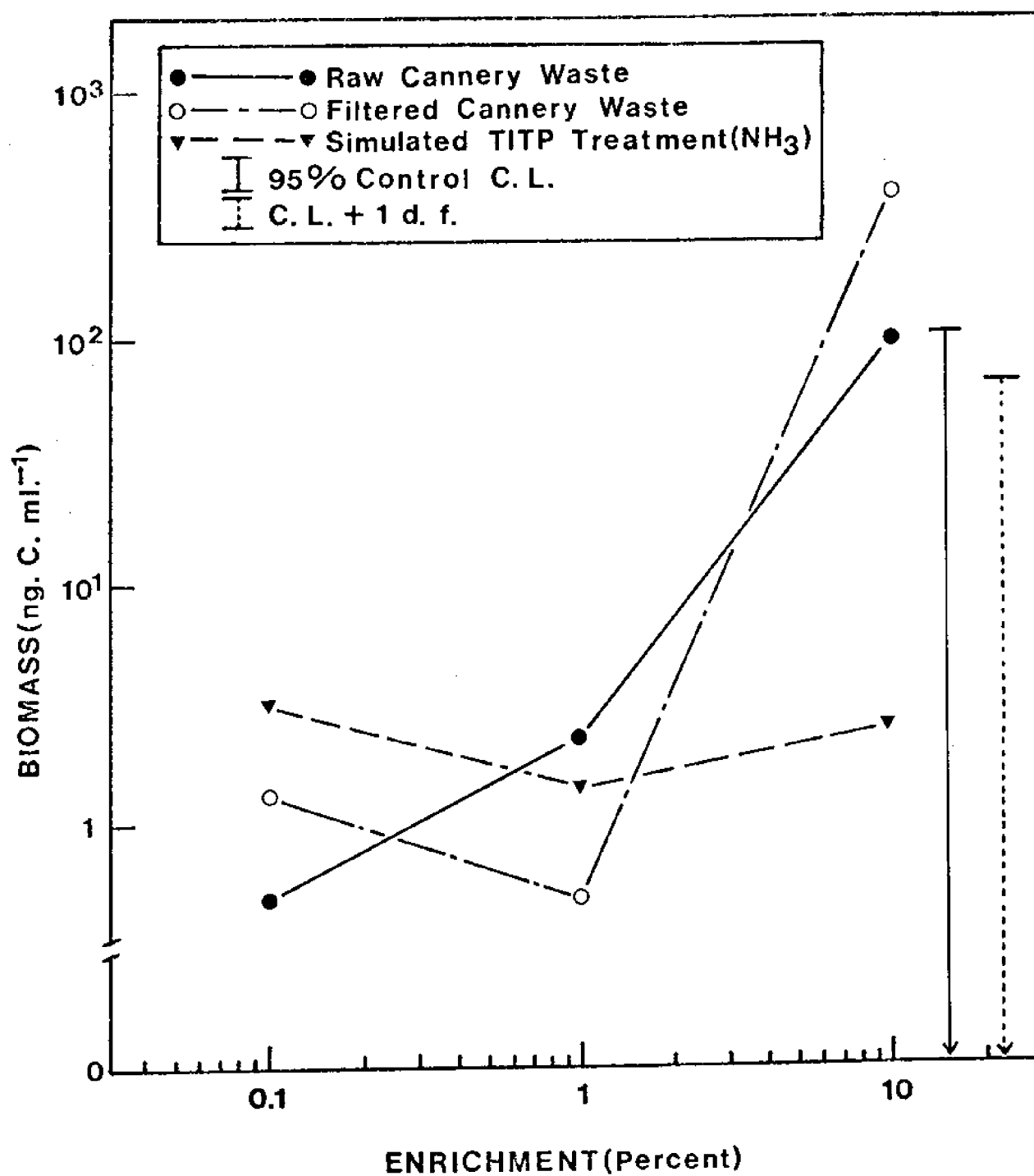


FIGURE 13. ENRICHMENT EFFECTS ON CILIATES (EXPERIMENT 2).

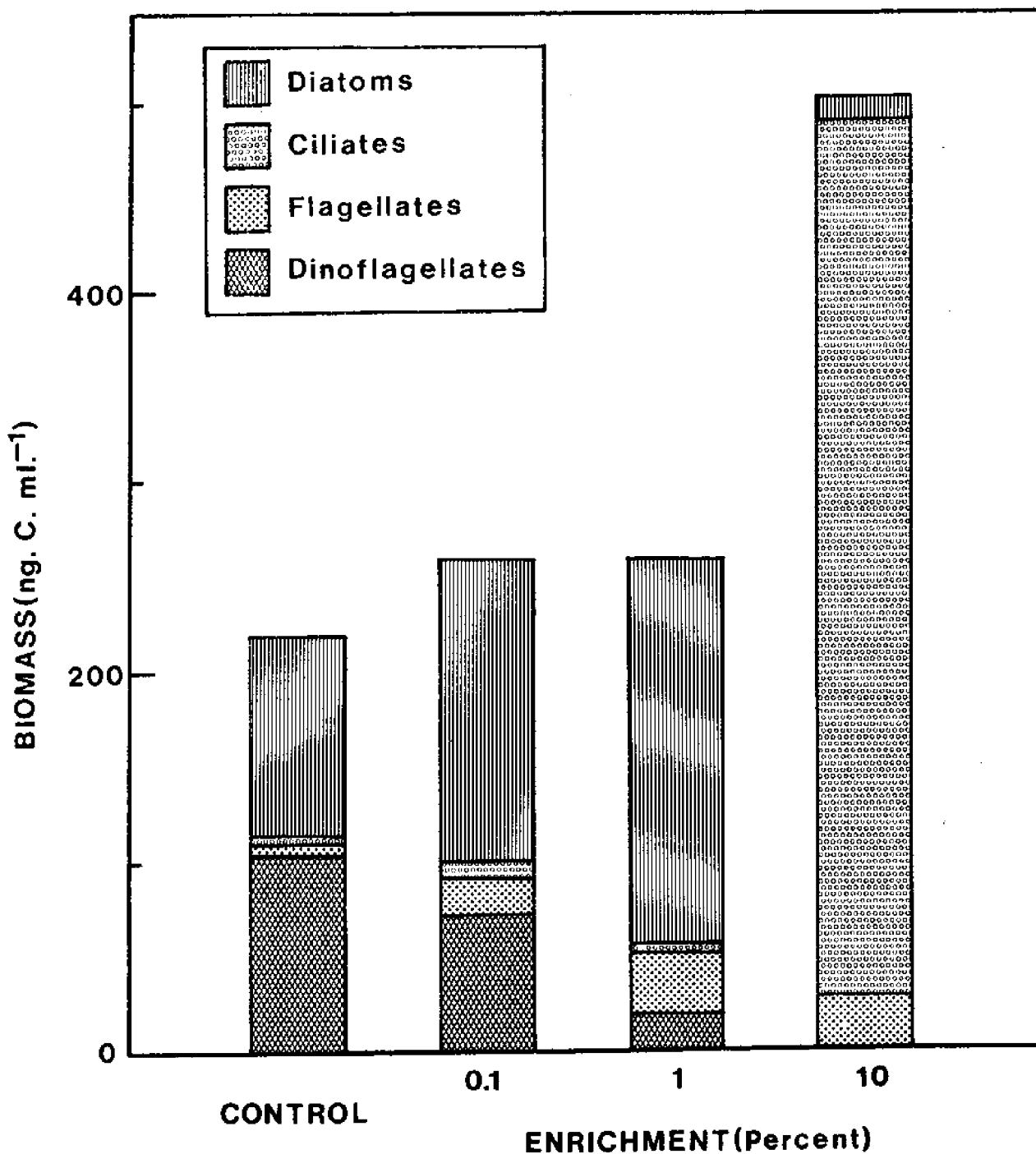


FIGURE 14. EFFECTS OF RAW CANNERY WASTE ON MICROPLANKTON (EXPERIMENT 1).

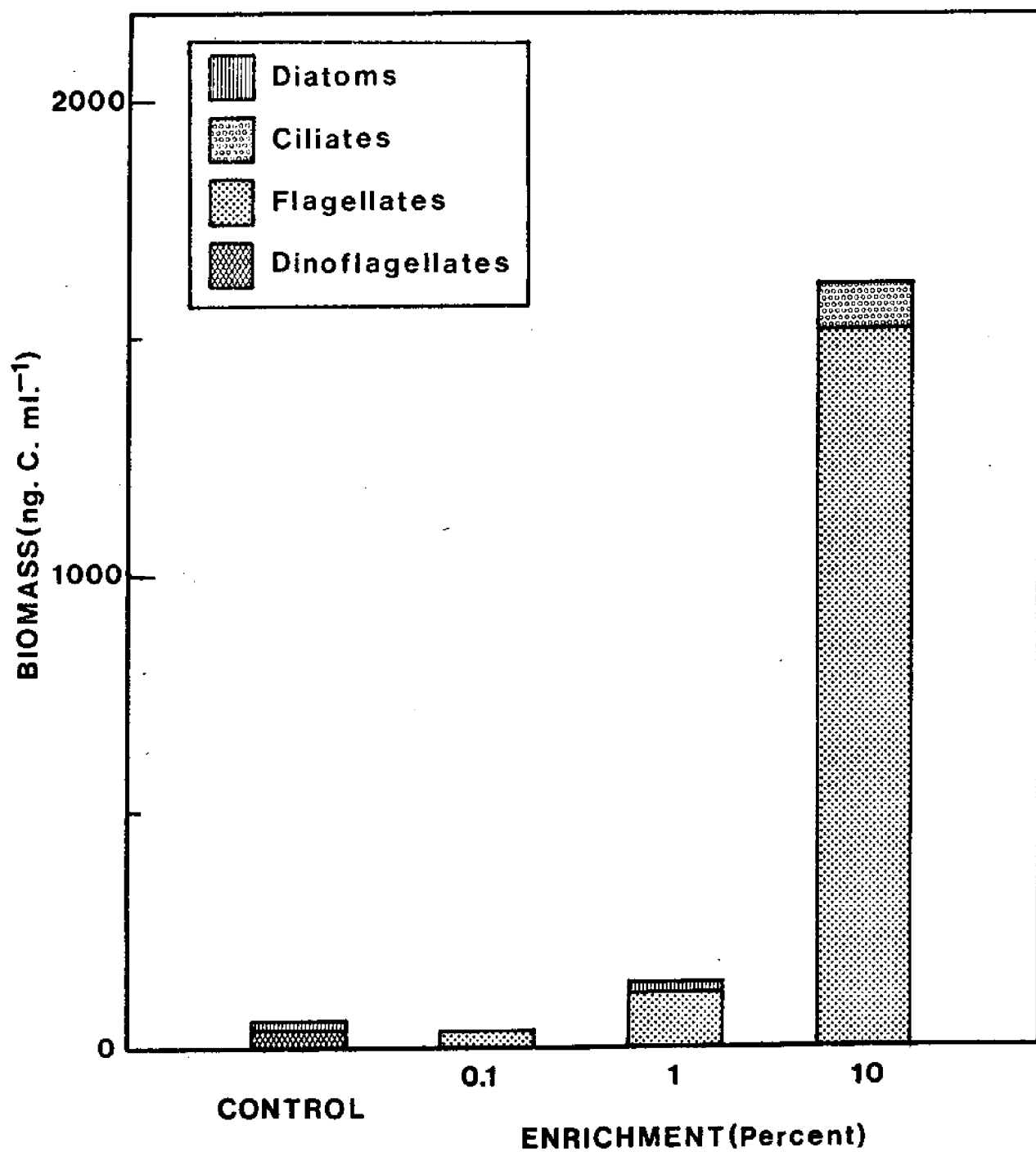


FIGURE 15. EFFECTS OF RAW CANNERY WASTE ON MICROPLANKTON (EXPERIMENT 2).

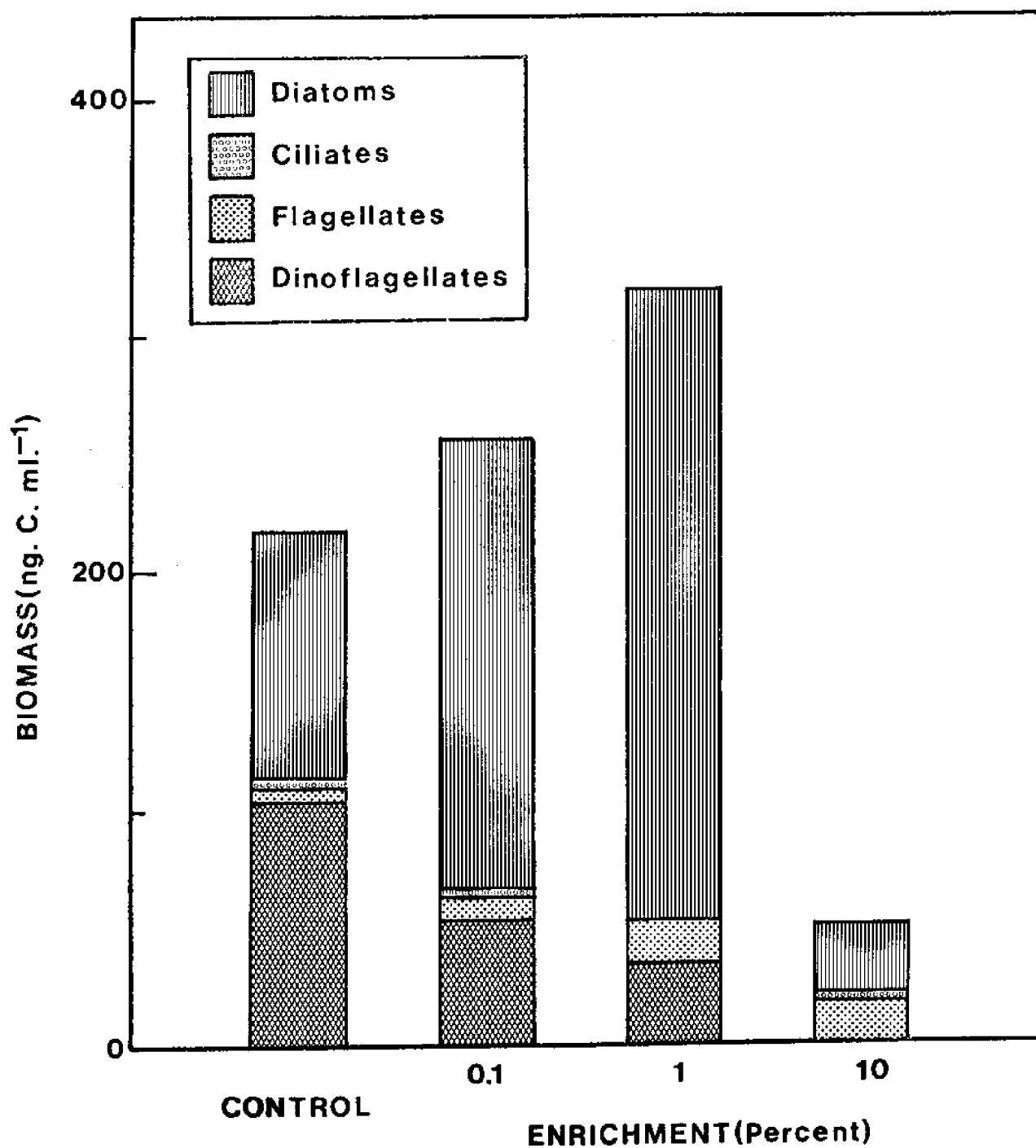


FIGURE 16. EFFECTS OF FILTERED CANNERY WASTE ON MICROPLANKTON (EXPERIMENT 1).

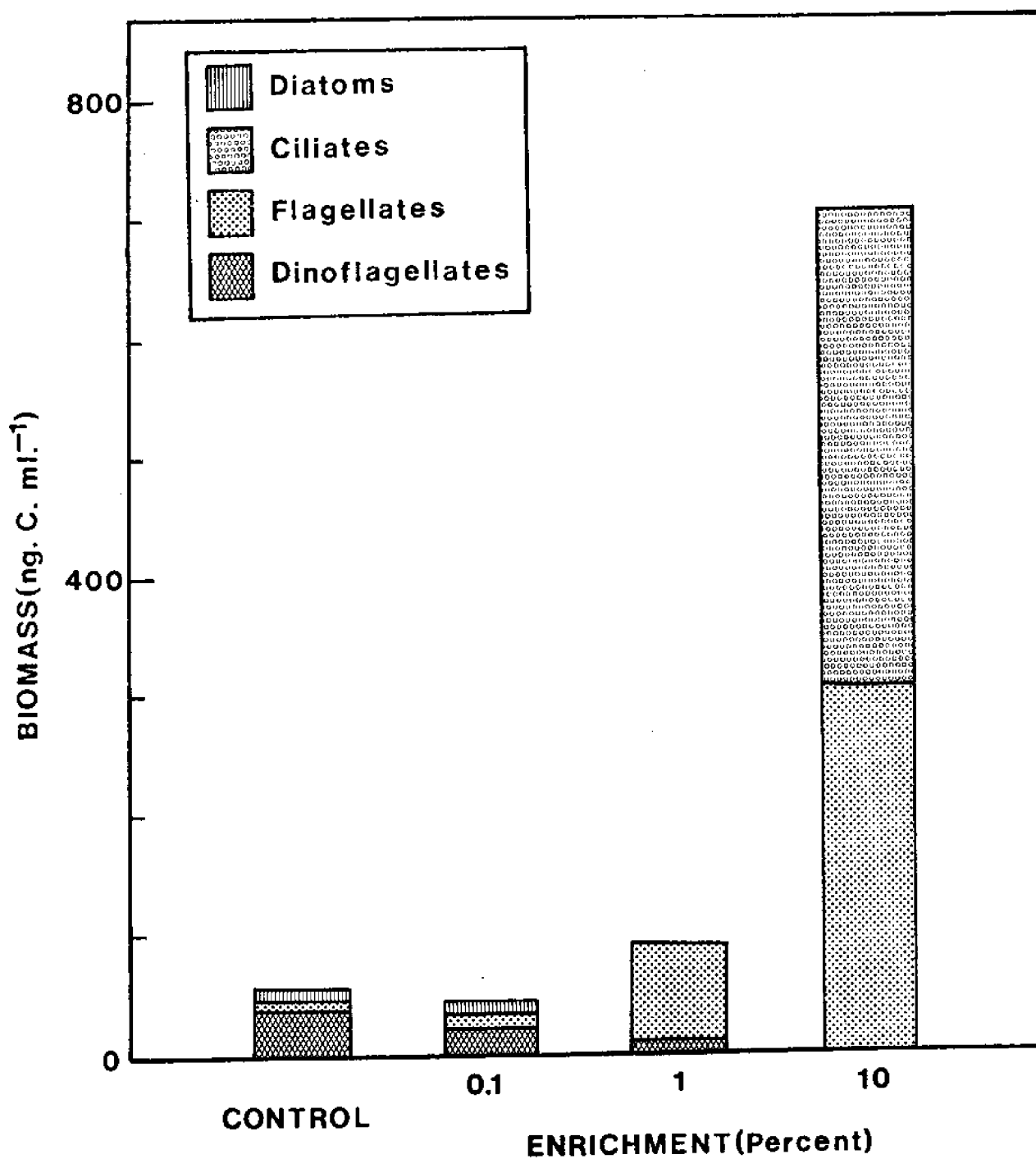


FIGURE 17. EFFECTS OF FILTERED CANNERY WASTE ON MICROPLANKTON (EXPERIMENT 2).

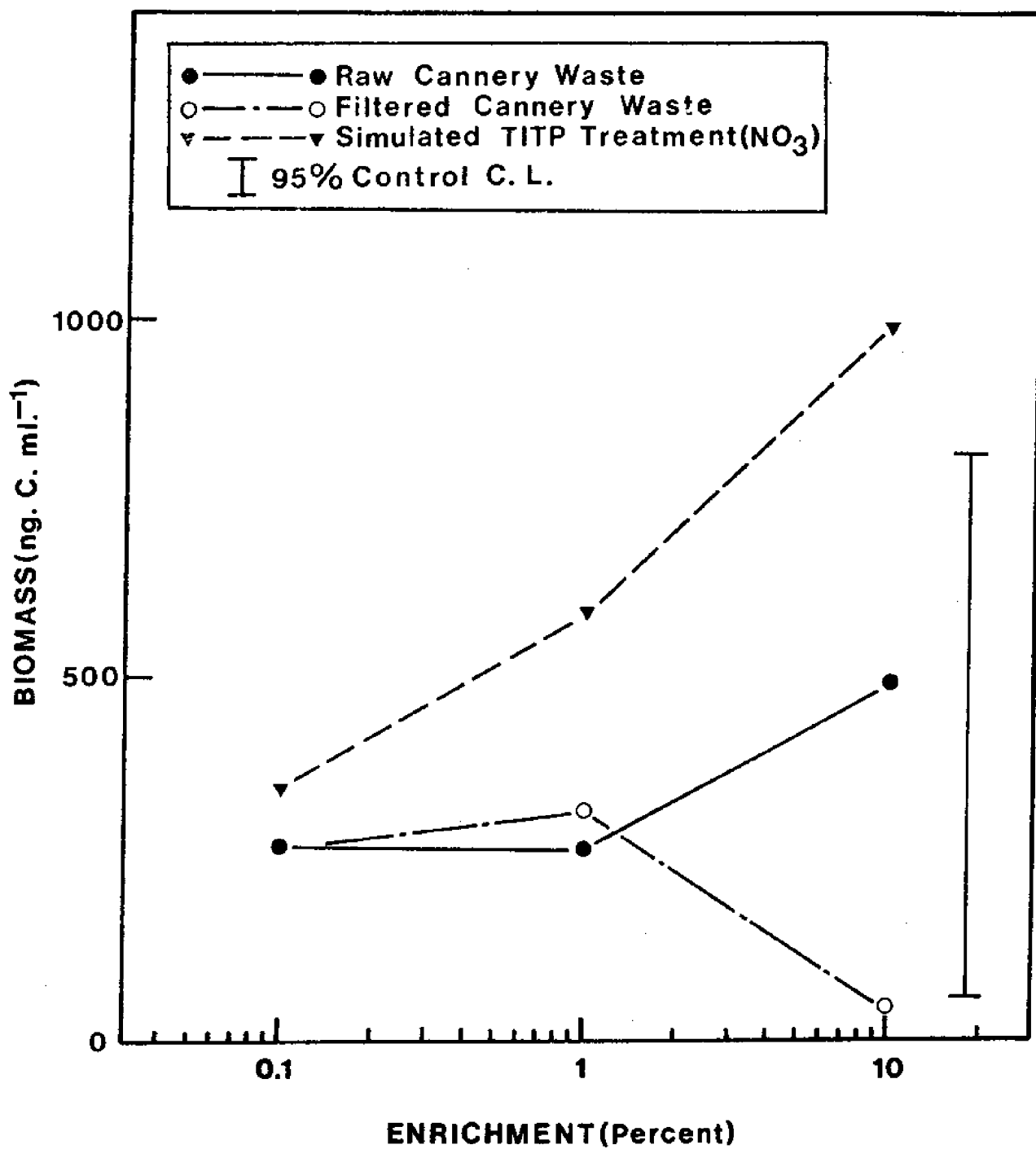


FIGURE 18. ENRICHMENT EFFECTS ON TOTAL MICROPLANKTON (EXPERIMENT 1).

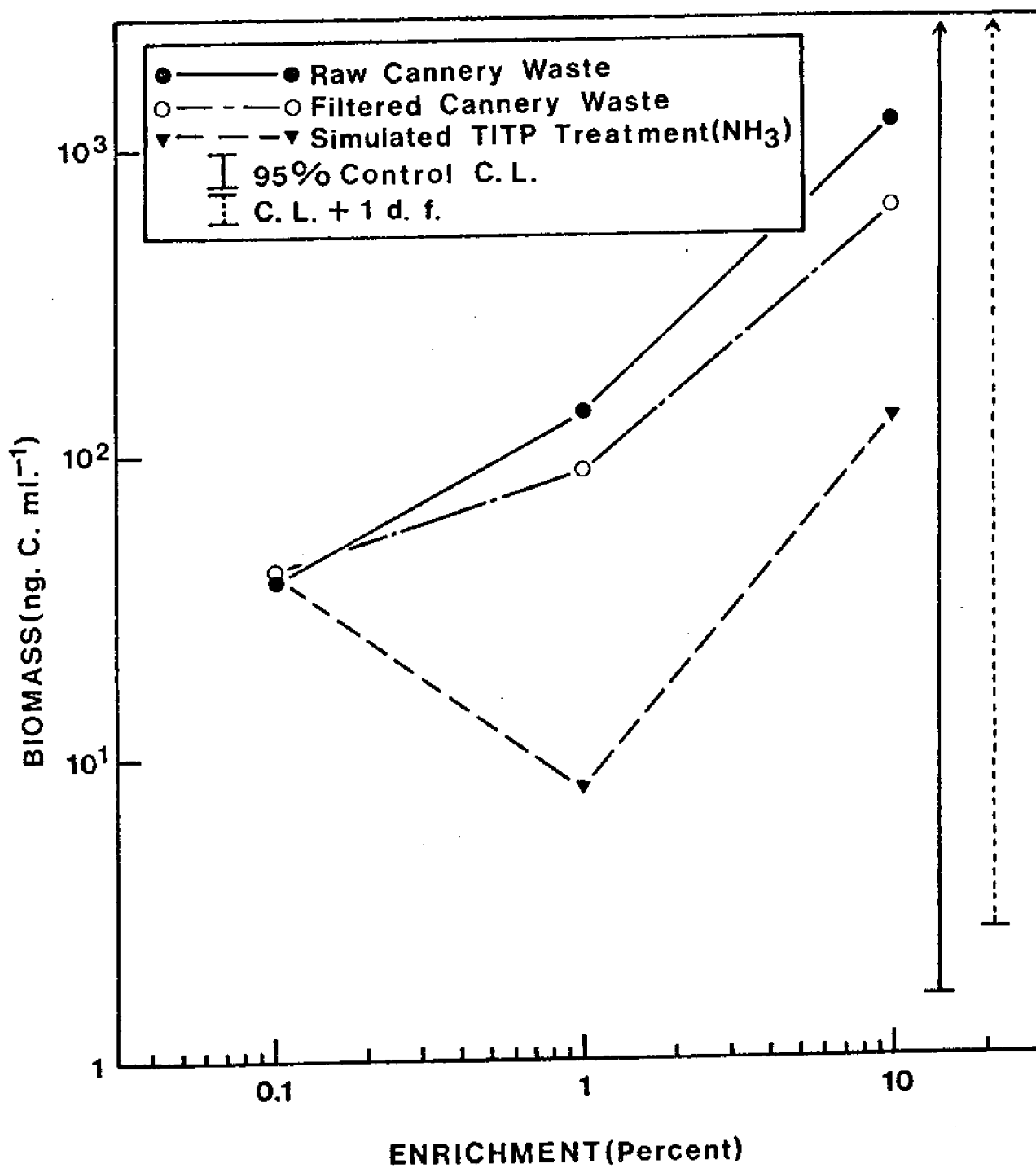


FIGURE 19. ENRICHMENT EFFECTS ON TOTAL MICROPLANKTON (EXPERIMENT 2).

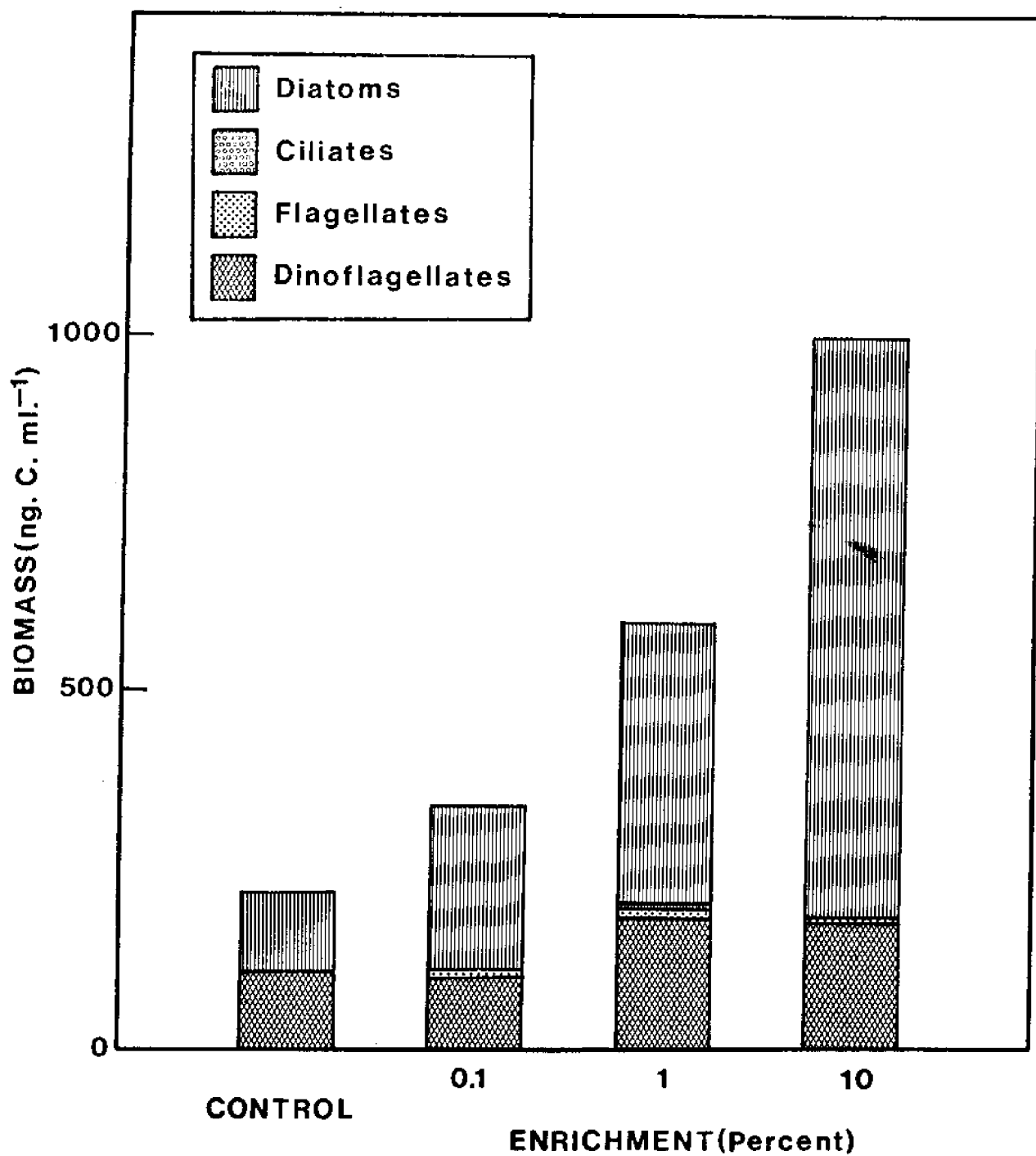


FIGURE 20. EFFECTS OF SIMULATED TITP TREATMENT (NO₃) ON MICROPLANKTON (EXPERIMENT 1).

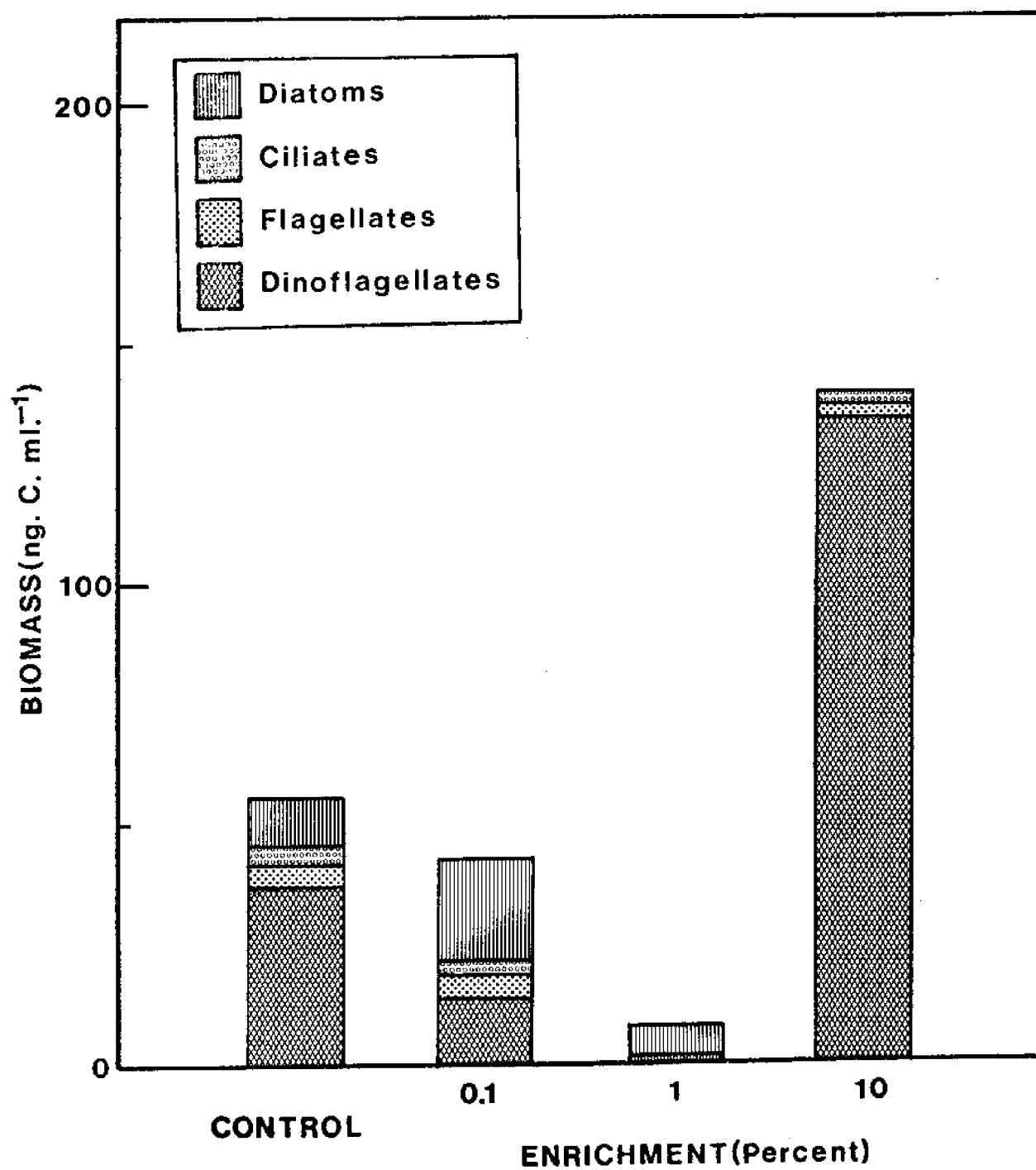


FIGURE 21. EFFECTS OF SIMULATED TITP TREATMENT (NH_3) ON MICROPLANKTON (EXPERIMENT 2).

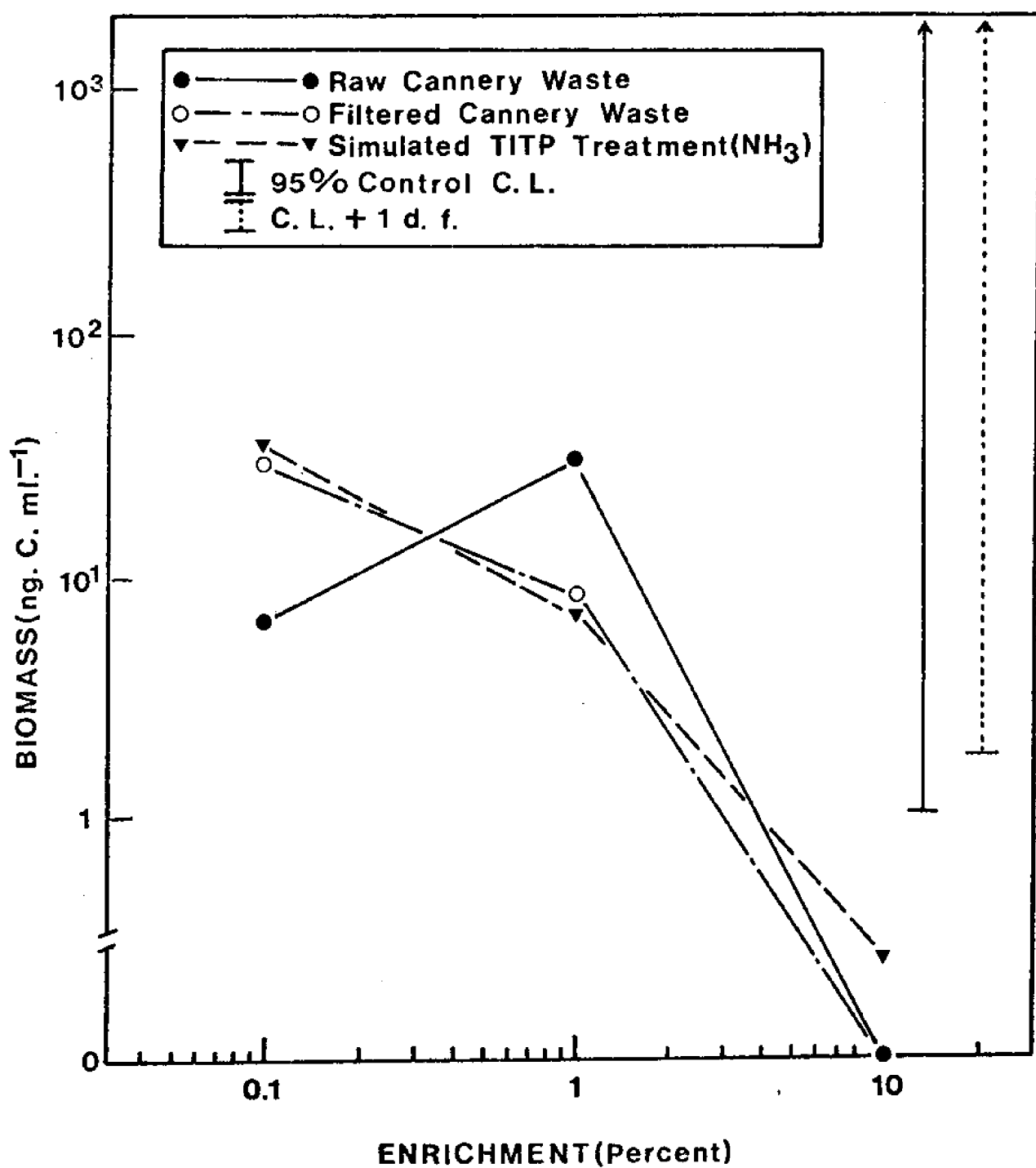


FIGURE 22. ENRICHMENT EFFECTS ON DIATOMS + DINOFLAGELLATES (EXPERIMENT 2) - *Protoperidinium crassipes* Kofoid EXCLUDED.

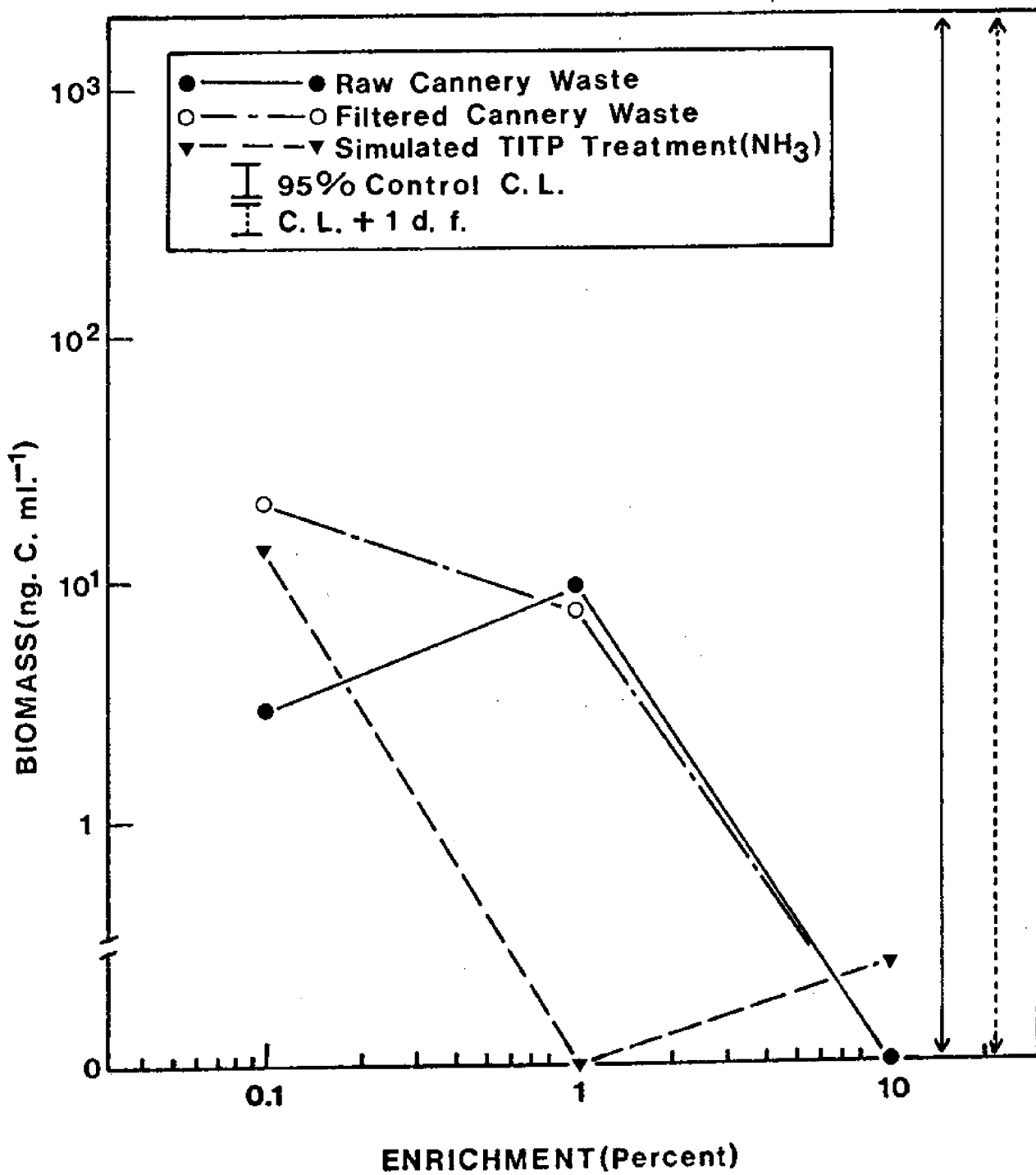


FIGURE 23. ENRICHMENT EFFECTS ON DINOFLAGELLATES
(EXPERIMENT 2) - *Protooperidinium crassipes*
Kofoid EXCLUDED.

Table A.1 Experiment 1 Controls Data (ng. Carbon x ml.⁻¹).

| | "Initial Controls" Means | 0.1% Control | 1% Control | 10% Control |
|-------------------------------|--------------------------------|-----------------|---------------|----------------|
| DINOFLAGELLATES | | | | |
| <i>Cochlodinium catenatum</i> | 58.710 | 62.265 | 80.055 | 56.928 |
| <i>Gonyaulax polyedra</i> | 35.030 | 13.701 | 18.268 | 4.567 |
| <i>Gerratum</i> spp. | 5.707 | 4.825 | 15.778 | 1.984 |
| <i>Prorocentrum</i> spp. | 0.661 | 0 | 1.739 | 0 |
| <i>Protoperdinium</i> spp. | 4.870 | 0 | 37.230 | 0 |
| Other Dinoflagellates | 4.211 | 2.967 | 6.099 | 0.714 |
| Total Dinoflagellates | 109.189 | 83.758 | 159.169 | 64.193 |
| DIATOMS | | | | |
| <i>Leptocylindrus danicus</i> | 2.072 | 16.956 | 44.190 | 21.235 |
| <i>Asterionella japonica</i> | 0.129 | 0.485 | 5.719 | 9.355 |
| <i>Ditylum brightwellii</i> | 5.435 | 32.612 | 0 | 16.306 |
| <i>Hemiaulis</i> spp. | 0 | 0 | 0 | 0 |
| <i>Chaetoceros</i> spp. | 10.612 | 111.712 | 29.972 | 23.759 |
| <i>Nitzschia</i> spp. | 0.268 | 3.213 | 4.154 | 1.837 |
| Other Diatoms | 1.503 | 51.104 | 12.902 | 13.497 |
| Total Diatoms | 20.020 | 216.082 | 96.937 | 85.989 |
| Diatoms + Dinoflagellates | 129.220 | 299.840 | 256.106 | 150.182 |
| FLAGELLATES | | | | |
| Nanoflagellate sp. | 5.760 | 5.760 | 5.760 | 5.760 |
| Other Flagellates | 0.402 | 0 | 1.036 | 0.097 |
| Total Flagellates | 6.142 | 5.760 | 6.796 | 5.857 |
| CILIATES | | | | |
| <i>Uronema</i> sp. | 0 | 0 | 0 | 0 |
| Oligotrichida, unid. | 2.881 | 0.079 | 0.471 | 0.314 |
| Other Ciliates | 6.711 | 0 | 2.876 | 2.876 |
| Total Ciliates | 9.592 | 0.079 | 3.347 | 3.190 |
| Flagellates + Ciliates | 15.734 | 5.839 | 10.143 | 9.047 |
| Total Microplankton | 144.943 | 305.600 | 266.249 | 159.229 |

Table A.2 Experiment 1 Cannery Waste Treatments Data (ng. Carbon x ml.⁻¹).

| | 0.1% | | 1% | | 10% | | 0.1% | | 1% | | 10% | |
|-------------------------------|---------|-------|---------|-------|---------|-------|----------|-------|----------|-------|----------|-------|
| | Raw | Waste | Raw | Waste | Raw | Waste | Filtered | Waste | Filtered | Waste | Filtered | Waste |
| DINOFLAGELLATES | | | | | | | | | | | | |
| <i>Cochlodinium catenatum</i> | 35.580 | | 0 | | 0 | | 39.140 | | 0 | | 0 | |
| <i>Gonyaulax polyedra</i> | 0 | | 0 | | 0 | | 4.567 | | 9.134 | | 0 | |
| <i>Ceratium</i> spp. | 24.170 | | 0.857 | | 2.841 | | 6.809 | | 4.628 | | 0 | |
| <i>Prorocentrum</i> spp. | 0.256 | | 0.769 | | 0 | | 0.531 | | 3.590 | | 0 | |
| <i>Protoperidinium</i> spp. | 9.564 | | 19.130 | | 0 | | 0 | | 0.904 | | 0 | |
| Other Dinoflagellates | 3.807 | | 0.637 | | 0 | | 3.327 | | 16.590 | | 0 | |
| Total Dinoflagellates | 73.380 | | 21.390* | | 2.841* | | 54.360 | | 34.850 | | 0* | |
| DIATOMS | | | | | | | | | | | | |
| <i>Leptocylindrus danicus</i> | 31.010 | | 45.910 | | 0 | | 35.840 | | 27.900 | | 1.638 | |
| <i>Asterionella japonica</i> | 7.707 | | 10.570 | | 0 | | 20.940 | | 54.340 | | 0.145 | |
| <i>Ditylum brightwellii</i> | 0 | | 73.380 | | 0 | | 0 | | 0 | | 16.310 | |
| <i>Hemianalis</i> spp. | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| <i>Chaetoceros</i> spp. | 51.930 | | 27.310 | | 9.761 | | 62.370 | | 101.600 | | 8.769 | |
| <i>Mitsuchia</i> spp. | 23.160 | | 37.860 | | 0.029 | | 50.280 | | 57.950 | | 3.602 | |
| Other Diatoms | 41.350 | | 5.794 | | 1.080 | | 20.140 | | 24.240 | | 0 | |
| Total Diatoms | 155.200 | | 200.800 | | 10.870 | | 189.600 | | 266.000 | | 30.460 | |
| Diatoms + Dinoflagellates | 228.580 | | 222.190 | | 13.711* | | 243.960 | | 300.850 | | 30.460* | |
| FLAGELLATES | | | | | | | | | | | | |
| Nanoflagellate sp. | 11.600 | | 31.490 | | 28.640 | | 6.820 | | 7.161 | | 18.220 | |
| Other Flagellates | 7.995 | | 0.265 | | 0 | | 2.315 | | 10.680 | | 0 | |
| Total Flagellates | 19.600* | | 31.760* | | 28.640* | | 9.135* | | 17.840* | | 18.220* | |
| CILIATES | | | | | | | | | | | | |
| <i>Uronema</i> sp. | 0 | | 0.324 | | 458.500 | | 0 | | 0.810 | | 3.726 | |
| Oligotrichida, unid. | 6.752 | | 0.157 | | 0 | | 3.926 | | 0.314 | | 0 | |
| Other Ciliates | 2.232 | | 2.876 | | 0 | | 0 | | 0 | | 0 | |
| Total Ciliates | 8.984 | | 3.357 | | 458.500 | | 3.926 | | 1.124 | | 3.726 | |
| Flagellates + Ciliates | 28.620* | | 35.110* | | 487.189 | | 13.040 | | 18.950 | | 21.950 | |
| Total Microplankton | 257.200 | | 257.300 | | 500.900 | | 257.000 | | 319.800 | | 52.410 | |

*Significant at the P<0.05 level.

Table A.3 Experiment 1 Simulated TITP Treatments (NO₃) Data (ng. Carbon x ml.⁻¹).

| | 0.1% Simulated TITP | 1% Simulated TITP | 10% Simulated TITP |
|-------------------------------|---------------------------|-------------------------|--------------------------|
| DINOFLAGELLATES | | | |
| <i>Cochlodinium catenatum</i> | 92.510 | 147.700 | 135.200 |
| <i>Gonyaulax polyedra</i> | 0 | 22.840 | 27.400 |
| <i>Ceratium</i> spp. | 5.952 | 11.900 | 13.690 |
| <i>Prorocentrum</i> spp. | 0.256 | 0.256 | 0.769 |
| <i>Protoperidinium</i> spp. | 0 | 0 | 0 |
| Other Dinoflagellates | 3.771 | 1.575 | 3.211 |
| Total Dinoflagellates | 102.500 | 184.300 | 180.300 |
| DIATOMS | | | |
| <i>Leptocylindrus danicus</i> | 24.820 | 65.950 | 96.900 |
| <i>Asterionella japonica</i> | 1.648 | 18.660 | 102.500 |
| <i>Ditylum brightwellii</i> | 32.610 | 0 | 57.070 |
| <i>Hemiaulis</i> spp. | 0 | 0 | 0 |
| <i>Chaetoceros</i> spp. | 130.100 | 251.500 | 431.400 |
| <i>Nitzschia</i> spp. | 5.866 | 19.030 | 33.160 |
| Other Diatoms | 34.670 | 33.020 | 88.220 |
| Total Diatoms | 229.700 | 388.200 | 809.300 |
| Diatoms + Dinoflagellates | 332.200 | 572.500 | 989.600* |
| FLAGELLATES | | | |
| Nanoflagellate sp. | 5.760 | 5.760 | 5.760 |
| Other Flagellates | 1.267 | 11.210 | 0.649 |
| Total Flagellates | 7.027 | 16.970 | 6.409 |
| CILIATES | | | |
| <i>Uronema</i> sp. | 0 | 0 | 0 |
| Oligotrichida, unid. | 0.393 | 0.314 | 0.314 |
| Other Ciliates | 0 | 4.464 | 0 |
| Total Ciliates | 0.393 | 4.778 | 0.314 |
| Flagellates + Ciliates | 7.400 | 21.700 | 6.700 |
| Total Microplankton | 339.600 | 594.200 | 996.300* |

*Significant at the P<0.05 level.

Table A.4 Experiment 2 Controls Data (ng. Carbon x ml.⁻¹).

| | "Initial Controls" | | 0.1% | | 1% | | 10% | |
|-------------------------------|-----------------------|---------|---------|---------|---------|---------|---------|---------|
| | Means | Control | Control | Control | Control | Control | Control | Control |
| DINOFIAGELLATES | | | | | | | | |
| <i>Cochlodinium catenatum</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Gonyaulax polyedra</i> | 9.134 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Ceratium</i> spp. | 0.971 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Prorocentrum</i> spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Protoperidinium</i> spp. | 1.423 | 134.269 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other Dinoflagellates | 0.037 | 0.357 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Dinoflagellates | 11.565 | 134.626 | 0 | 0 | 0 | 0 | 0 | 0 |
| DIATOMS | | | | | | | | |
| <i>Leptocylindrus danicus</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Asterionella japonica</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Ditylum brightwellii</i> | 0 | 0 | 0 | 0 | 8.153 | 0 | 0 | 0 |
| <i>Hemiaulis</i> spp. | 0.360 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Chaetoceros</i> spp. | 0.551 | 0.414 | 0 | 0 | 3.205 | 13.235 | 13.235 | 13.235 |
| <i>Nitzschia</i> spp. | 0.005 | 0.387 | 0 | 0 | 0.331 | 2.583 | 2.583 | 2.583 |
| Other Diatoms | 0.800 | 6.317 | 0 | 0 | 1.143 | 10.893 | 10.893 | 10.893 |
| Total Diatoms | 1.716 | 7.118 | 0 | 0 | 12.832 | 26.711 | 26.711 | 26.711 |
| Diatoms + Dinoflagellates | 13.282 | 141.744 | 0 | 0 | 12.832 | 26.711 | 26.711 | 26.711 |
| FLAGELLATES | | | | | | | | |
| Nanoflagellate sp. | 0 | 4.144 | 0 | 0 | 5.801 | 9.945 | 9.945 | 9.945 |
| Other Flagellates | 0.183 | 0.549 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Flagellates | 0.183 | 4.693 | 0 | 0 | 5.801 | 9.945 | 9.945 | 9.945 |
| CILIATES | | | | | | | | |
| <i>Uronema</i> sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Oligotrichida, unid. | 0.079 | 3.297 | 0 | 0 | 9.657 | 2.120 | 2.120 | 2.120 |
| Other Ciliates | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Ciliates | 0.079 | 3.297 | 0 | 0 | 9.657 | 2.120 | 2.120 | 2.120 |
| Flagellates + Ciliates | 0.261 | 7.990 | 0 | 0 | 15.458 | 3.554 | 3.554 | 3.554 |
| Total Microplankton | 13.543 | 149.734 | 0 | 0 | 28.290 | 30.265 | 30.265 | 30.265 |

Table A.5 Experiment 2 Cannery Waste Treatments Data (ng. Carbon x ml.⁻¹).

| | 0.1% | | 1% | | 10% | | 0.1% | | 1% | | 10% | |
|-------------------------------|---------|-------|----------|-------|------------|-------|----------|-------|----------|-------|----------|-------|
| | Raw | Waste | Raw | Waste | Raw | Waste | Filtered | Waste | Filtered | Waste | Filtered | Waste |
| DINOFLAGELLATES | | | | | | | | | | | | |
| <i>Cochlodinium catenatum</i> | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| <i>Gonyaulax polyedra</i> | 0 | | 9.134 | | 0 | | 9.134 | | 4.567 | | 0 | |
| <i>Ceratium</i> spp. | 2.914 | | 0 | | 0 | | 7.812 | | 2.914 | | 0 | |
| <i>Prorocentrum</i> spp. | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| <i>Protoperidinium</i> spp. | 0 | | 0 | | 0 | | 4.269 | | 0 | | 0 | |
| Other Dinoflagellates | 0 | | 0.357 | | 0 | | 0 | | 0 | | 0 | |
| Total Dinoflagellates | 2.914 | | 9.491 | | 0 | | 21.215 | | 7.481 | | 0 | |
| DIATOMS | | | | | | | | | | | | |
| <i>Leptocylindrus danicus</i> | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| <i>Asterionella japonica</i> | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| <i>Ditylum brightwellii</i> | 0 | | 8.153 | | 0 | | 0 | | 0 | | 0 | |
| <i>Hemiaulis</i> spp. | 1.512 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| <i>Chaetoceros</i> spp. | 0.321 | | 11.374 | | 0 | | 5.067 | | 0.517 | | 0 | |
| <i>Nitzschia</i> spp. | 0.732 | | 0.474 | | 0 | | 0.918 | | 0.301 | | 0 | |
| Other Diatoms | 1.025 | | 0 | | 0 | | 2.576 | | 0 | | 0 | |
| Total Diatoms | 3.590 | | 20.001 | | 0 | | 8.561 | | 0.818 | | 0 | |
| Diatoms + Dinoflagellates | 6.504 | | 29.492 | | 0* | | 29.776 | | 8.299 | | 0* | |
| FLAGELLATES | | | | | | | | | | | | |
| Nanoflagellate sp. | 29.835 | | 114.367 | | 1,513.414 | | 11.602 | | 83.704 | | 304.151 | |
| Other Flagellates | 0.552 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| Total Flagellates | 30.387* | | 114.367* | | 1,153.414* | | 11.602 | | 83.704* | | 304.151* | |
| CILIATES | | | | | | | | | | | | |
| <i>Uronema</i> sp. | 0.486 | | 2.268 | | 100.764 | | 1.296 | | 0.486 | | 400.626 | |
| Oligotrichida, unid. | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| Other Ciliates | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| Total Ciliates | 0.486 | | 2.268 | | 100.764* | | 1.296 | | 0.486 | | 400.626 | |
| Flagellates + Ciliates | 32.873 | | 116.635 | | 1,614.178* | | 12.898 | | 84.190 | | 704.777* | |
| Total Microplankton | 39.377 | | 146.127 | | 1,614.178* | | 42.674 | | 92.489 | | 704.777 | |

*Significant at the P<0.05 level.

•With 1 more degree of freedom, would be significant at the P<0.05 level.

Table A.6 Experiment 2 Simulated TTP Treatments(NH₃) Data (ng. Carbon x ml.⁻¹).

| | 0.1% Simulated TTP | 1% Simulated TTP | 10% Simulated TTP |
|-------------------------------|--------------------------|------------------------|-------------------------|
| DINOFLAGELLATES | | | |
| <i>Cochlodinium catenatum</i> | 0 | 0 | 0 |
| <i>Gonyaulax polyedra</i> | 0 | 0 | 0 |
| <i>Ceratium</i> spp. | 0 | 0 | 0 |
| <i>Prorocentrum</i> spp. | 0 | 0 | 0.256 |
| <i>Protoperidinium</i> spp. | 0 | 0 | 134.269 |
| Other Dinoflagellates | 13.647 | 0 | 0 |
| Total Dinoflagellates | 13.647 | 0 | 134.525 |
| DIATOMS | | | |
| <i>Leptocylindrus danicus</i> | 0 | 0 | 0 |
| <i>Asterionella japonica</i> | 0 | 0 | 0 |
| <i>Ditylum brightwellii</i> | 0 | 0 | 0 |
| <i>Hemiaulis</i> spp. | 14.244 | 0.216 | 0 |
| <i>Chaetoceros</i> spp. | 6.721 | 0 | 0 |
| <i>Nitzschia</i> spp. | 0.531 | 0.158 | 0 |
| Other Diatoms | 0 | 6.307 | 0 |
| Total Diatoms | 21.496 | 6.681 | 0 |
| Diatoms + Dinoflagellates | 35.143 | 6.681 | 134.525 |
| FLAGELLATES | | | |
| Nanoflagellate sp. | 4.972 | 0 | 2.486 |
| Other Flagellates | 0 | 0 | 0 |
| Total Flagellates | 4.972 | 0* | 2.486 |
| CILIATES | | | |
| <i>Uronema</i> sp. | 0 | 0 | 0 |
| Oligotrichida, unid. | 3.140 | 1.413 | 2.512 |
| Other Ciliates | 0 | 0 | 0 |
| Total Ciliates | 3.140 | 1.413 | 2.512 |
| Flagellates + Ciliates | 8.112 | 1.413 | 4.998 |
| Total Microplankton | 43.255 | 8.094 | 139.523 |

*Significant at the P<0.05 level.

MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA. PART 14.

THE INFLUENCE OF THE LOS ANGELES RIVER
ON BENTHIC POLYCHAETOUS ANNELIDS

by

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ABSTRACT. The Los Angeles River provides major drainage via flood control channel for much of the Los Angeles Basin. The purpose of this study was to determine whether or not this river has any adverse effect on the subtidal benthic fauna, especially during periods of heavy run-off. The polychaete population was reduced at the station nearest the mouth whenever the rainfall for any month was approximately 5.0 cm or greater. Repopulation was rapid by *Capitella capitata*. Species diversity increased with increasing distance from the mouth of the river. A total of 90 species of polychaetes was taken during the 15 month study period.

INTRODUCTION

The Los Angeles River drains the majority of the rainfall which falls within Los Angeles Basin; however, no previous study has been undertaken thus far to determine whether or not this fresh water influx has any adverse effect on benthic polychaetous annelids in Los Angeles-Long Beach Harbors. Typically, rainfall on the Los Angeles Basin is confined to infrequent rains during the winter months followed by a long period through much of spring to mid-fall in which there is little precipitation. Therefore, through much of the year the benthos at, and off the mouth of Los Angeles River is only exposed to ambient seawater. Previous benthic studies in the vicinity of the mouth of the Los Angeles River are limited (Marine Biological Consultants, 1975). One sample was taken downstream from the present Station 2. The benthos was characterized by the presence of the polychaetes *Tharyx* sp., *Cossura candida*, and Capitellidae (= *Capitita ambiseta*). Benthic studies have been undertaken in nearby Los Angeles-Long Beach Harbors over the past 20 years; the latest and most extensive was reported by Harbor Projects (1976). Much of the outer harbor area is characterized by the polychaetes *Tharyx* sp., *Cossura candida*, *Haploscoloplos elongatus*, and *Paraprionospio pinnata*.

The purpose of this benthic study is to determine whether or not the seasonal fresh water run-off of the Los Angeles River has any effect on the benthic fauna.

METHODS

Bimonthly benthic samples were taken at six stations located offshore from the City of Long Beach area (Figure 1). Samples were taken with a Shipek grab which covers a surface area of 0.04 m². Samples were washed through a 0.5 mm mesh screen and preserved with formalin for 48 hours. Additional washing was done in the laboratory and the material retained on the screen transferred to 70% isopropyl alcohol. Polychaetes were counted and identified to the lowest possible taxon.

Water samples were taken at approximately two feet above the bottom for salinity measurements. The Winkler titration method (Strickland and Parsons, 1972) was performed to determine the salinity values.

The Shannon-Wiener diversity index (H') was calculated for each station for each sampling period, using the formula:

$$H' = - \sum p_i \log p_i$$

where: $p_i = \frac{N_i}{N}$ (Number of individuals of a species)
(Total number of individuals per sample)

and log = natural log (base e)

RESULTS

The results of the collections of polychaetous annelids taken at six stations at eight times over a 14 month period are summarized according to species occurrence (Table 1) and quantitative occurrence by station (Tables 2-7). A total of 15,925 specimens in 90 species were collected during the period of study. Eight species accounted for nearly 90% of the specimens, namely *Cossura candida* (25%) *Capitella capitata* (22%), *Tharyx* sp. (8.4%), *Prionospio cirrifera* (6.7%) *Nephtys cornuta franciscana*, *Chaetozone corona*, *Streblosoma crassibranchiata*, and *Armandia bioculata*. In general, as one proceeded from Station 1 at the mouth of the river to Station 6, there was an increase in the number of species present per sample; in contrast, however, the maximum number of specimens per sample was at Station 3, followed by 1 and 2. Station 6, which had the greatest average number of species present, had next to the smallest number of specimens present. When the diversity index is calculated, a direct relationship is found between species diversity and the distance from the mouth of the river.

Essentially two benthic communities were present in the study area. Station 1 was dominated by *Capitella capitata*. Stations 2 through 6 were characterized by the polychaetes *Capitita ambiseta*, *Cossura candida*, *Tharyx* sp., plus some additional common species. By employing Morisita's (1959) index of similarity (I_M), Stations 3 and 4 are similar as are 5 and 6, with Station 2 separated from these four stations and Station 1.

Salinity values (Table 8) ranged between 32.50/00 and 33.50/00 throughout the study period, except in January 1978. During this period, there was a slight reduction in salinity at Station 1 from 32.50/00 to 30.00/00.

Monthly rainfall data for the City of Long Beach are summarized in Table 9 from October 1976 through January 1978; these data were correlated with the diversity indices of each station for each collecting period and summarized by station in Table 10. The benthic population at Station 1 was the only area adversely affected by run-off from rains during the 15 month period of study. During this period, rainfall was heaviest in January 1977, May 1977, August 1977 and in the December 1977-January 1978 period which coincided with a reduction in the number of species and specimens each time. Recovery following the rainfall was rapid and was largely the result of a build-up of the population of *Capitella capitata*. While not evident from correlations, depressions in populations were noted at least once at each station which was generally noted at the time of the January collection.

DISCUSSION

The benthic polychaete fauna offshore from the City of Long Beach is rich and varied, especially at those stations located at a distance from the mouth of the Los Angeles River. While eight species accounted for nearly 900/00 of the individuals, the remaining species are known from Los Angeles-Long Beach Harbors or offshore waters (Marine Biological Consultants, 1975; Harbor Environmental Projects, 1976).

The presence of *Capitella capitata*, an indicator of a stressed environment, in large numbers at Station 1 was not surprising in view of the accumulation in the river bed of plant debris, street drainage and industrial pollutants. This station was also the one subjected to the greatest effect by the fresh water run-off and scouring associated with heavy rainfall. Since *Capitella* is an opportunistic species, in the absence of any competitors it was able to build up a large population in a relatively short time.

Stone and Reish (1965) found that an intertidal estuarine population of polychaetes, including *Capitella*, was reduced whenever the local rainfall exceed 1.25 cm. Repopulation was rapid and was probably from specimens living subtidally. Apparently the seemingly minor effect of run-

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Stone and Reish (1965) found that an intertidal estuarine population of polychaetes, including *Capitella*, was reduced whenever the local rainfall exceed 1.25 cm. Repopulation was rapid and was probably from specimens living subtidally. Apparently the seemingly minor effect of run-

off on benthic fauna at Stations 2 through 6 is due to movement of a salt water wedge up the river bottom as the lighter fresh water floats seaward on the surface. Rapid repopulation may be the result of the fact that many of the local species either reproduce throughout the year or have an extended period of reproduction. The fresh water run-off apparently has only a limited effect on the subtidal benthos in the offshore Long Beach City area.

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Table 1. Systematic list of the benthic polychaetous annelids collected off Long Beach, California 1976-1978.

Family Polynoidae

- Harmothoe crassiacirrata* Johnson, 1897
- Harmothoe imbricata* (Linnaeus, 1767)
- Harmothoe lunulata* (delle Chiaje, 1841)
- Harmothoe priops* Hartman, 1961

Family Sigalionidae

- Sthenelais tertiaglabra* Moore, 1910
- Sthenelais verruculosa* Johnson, 1897
- Sthenelanella uniformis* Moore, 1910

Family Phyllodocidae

- Anaitides longipes* (Kinberg, 1866)
- Anaitides* sp.
- Anaitides williamsi* Hartman, 1936
- Eteone dilatata* Hartman, 1936
- Eumida bifoliata* (Moore, 1909)

Family Hesionidae

- Gyptis brevipalpa* (Hartmann-Schroeder, 1959)

Family Pilargiidae

- Ancistrosyllis hamata* (Hartman, 1960)
- Pilargis berkeleyi* Monro, 1933
- Sigambra tentaculata* (Treadwell, 1941)

Family Syllidae

- Eusyllis transecta* Hartman, 1966
- Exogone gemmifera* Pagenstecher, 1862
- Exogone lourei* Berkeley and Berkeley, 1938

Family Nereidae

- Nereis procera* Ehlers, 1868

Family Nephtyidae

- Nephtys caecoides* Hartman, 1938
- Nephtys cornuta franciscana* Clark and Jones, 1955

Family Glyceridae

- Glycera americana* Leidy, 1855
- Glycera* sp.
- Glycera tessellata* Grube, 1863

Family Goniadidae

- Glycinde armigera* Moore, 1911
- Goniada brunnea* Treadwell, 1906
- Goniada littorea* Hartman, 1950

Family Onuphidae

Diopatra splendidissima Kinberg, 1865

Diopatra sp.

Nothria elegans (Johnson, 1901)

Nothria iridescens (Johnson, 1901)

• *Nothria pallida* Moore, 1911

Nothria sp.

Onuphid

Family Eunicidae

Marphysa belli oculata Treadwell, 1921

Marphysa disjuncta Hartman, 1961

Marphysa sp.

Family Lumbrineridae

Lumbrineris sp.

Family Arabellidae

Drilonereis falcata Moore, 1911

• *Drilonereis filium* (Claparede, 1868)

Family Dorvilleidae

Dorvillea sp.

Ophryotrocha sp.

Schistomeringos longicornis (Ehlers, 1901)

Family Orbiniidae

Haploscoloplos elongatus (Johnson, 1901)

Family Paraonidae

Acesta catherinae (Laubier, 1967)

Acesta cerrutii (Laubier, 1966)

Tauberia oculata (Hartman, 1957)

Family Spionidae

Boccardia basilaria Hartman, 1961

Laonice cirrata (Sars, 1851)

Paraprionospio pinnata (Ehlers, 1901)

Polydora caulleryi Mesnil, 1897

Polydora citrona Hartman, 1941

Polydora ligni Webster, 1879

Polydora limicola Annenkova, 1934

Polydora socialis (Schmarda, 1861)

Polydora sp.

Polydora websteri Hartman, 1943

Prionospio cirrifera Wren, 1883

Prionospio heterobranchia-neuportensis Reish, 1959

Prionospio pygmaeus Hartman, 1961

Prionospio sp.

Pseudopolydora paucibranchiata (Okuda, 1937)

Spiophanes berkeleyorum Pettibone, 1962

Spiophanes bombyx (Claparede, 1870)

Spiophanes missionensis Hartman, 1941

- Family Poecilochaetidae
Poecilochaetus johnsoni Hartman, 1939
- Family Chaetopteridae
Spiochaetopterus costarum (Claparede, 1870)
- Family Cirratulidae
Chaetozone corona Berkeley and Berkeley, 1941
Tharyx sp.
- Family Cossuridae
Cossura candida Hartman, 1955
- Family Scalibregmidae
Scalibregma inflatum Rathke, 1843
- Family Opheliidae
Armandia bioculata Hartman, 1938
- Family Capitellidae
Capitella capitata (Fabricius, 1780)
Capitita ambiseta Hartman, 1947
- Family Maldanidae
Maldanid
- Family Pectinariidae
Pectinaria californiensis Hartman, 1941
- Family Ampharetidae
Ampharete labrops Hartman, 1961
Ampharetid
Amphicteis scaphobranchiata Moore, 1906
Amphicteis sp.
Melinna oculata Hartman, 1969
- Family Terebellidae
Amaeana occidentalis (Hartman, 1944)
Pista cristata (Müller, 1776)
Pista disjuncta Moore, 1923
Streblosoma crassibranchia Treadwell, 1914
- Family Sabellidae
Chone minuta Hartman, 1944
Chone mollis (Bush, 1904)
Euchone incolor Hartman, 1965
- Polychaete, unidentified
-

Table 2. Number of species and specimens of polychaetous annelids collected from Station 1, Long Beach, California 1976-1978.

| Species | 11/76 | 1/77 | 3/77 | 5/77 | 7/77 | 9/77 | 11/77 | 1/78 |
|------------------------------------|-------|------|------|------|------|------|-------|------|
| <i>Anaitides williamsi</i> | | | 1 | | | | | |
| <i>Armandia bioculata</i> | | | 23 | | 91 | 1 | 25 | |
| <i>Capitella capitata</i> | 210 | 3 | 545 | 27 | 792 | 280 | 1494 | 117 |
| <i>Capitita ambiseta</i> | 1 | | 2 | | 87 | | 23 | |
| <i>Cossura candida</i> | 2 | | | 1 | 1 | | | |
| <i>Diopatra splendidissima</i> | | | | | 1 | | | |
| <i>Diopatra</i> sp. | | | 1 | | 1 | 1 | | |
| <i>Dorvillea</i> sp. | | | | | 1 | | | |
| <i>Eumida bifoliata</i> | | | | | | 7 | | |
| <i>Glycera americana</i> | | 1 | | | | | | |
| <i>Glycera</i> sp. | | | 3 | | | | | |
| <i>Harmothoe lunulata</i> | | | 1 | | | | | |
| <i>Nephtys cornuta franciscana</i> | | | 1 | | | | | |
| <i>Ophryotrocha</i> sp. | | | | | | 2 | | |
| <i>Paraprionospio pinnata</i> | | | 3 | | | | | |
| <i>Pectinaria californiensis</i> | | | 4 | | | | | |
| <i>Poecilochaetus johnsoni</i> | | | 1 | | | | | |
| <i>Polydora ligni</i> | | | | | 32 | 1 | 1 | |
| <i>Prionospio cirrifera</i> | | | 3 | | | | | |
| <i>Prionospio pygmaeus</i> | | | | | | | 1 | |
| <i>Prionospio</i> sp. | | | 1 | | | | | |
| <i>Schistomeringos longicornis</i> | 17 | 1 | | | | | 4 | |
| <i>Spiophanes missionensis</i> | | | 1 | | | | | |
| <i>Tharyx</i> sp. | 1 | | | | 3 | | | |
| Total number of specimens | 231 | 5 | 589 | 28 | 1009 | 285 | 1515 | 117 |
| Total number of species | 5 | 3 | 14 | 2 | 9 | 5 | 7 | 1 |
| Average number of specimens | 472.4 | | | | | | | |
| Average number of species | 5.8 | | | | | | | |

Table 3. Number of species and specimens of polychaetous annelids collected from Station 2, Long Beach, California 1976-1978.

| Species | 11/76 | 1/77 | 3/77 | 5/77 | 7/77 | 9/77 | 11/77 | 1/78 |
|---------------------------------------|-------|------|------|------|------|------|-------|------|
| <i>Amphicteis scaphobranchiata</i> | | | | | | 1 | | |
| <i>Anaitides longipes</i> | | | | 1 | | | | |
| <i>Armandia bioculata</i> | 1 | | | | | 10 | 79 | 4 |
| <i>Capitella capitata</i> | | | 1 | 27 | | | | |
| <i>Capitita ambiseta</i> | 228 | 102 | 54 | | 36 | 241 | 529 | 413 |
| <i>Chaetozone corona</i> | 1 | 9 | 2 | | | 11 | 1 | |
| <i>Cossura candida</i> | 43 | 10 | 8 | 5 | 25 | 32 | 461 | 84 |
| <i>Diopatra</i> sp. | 1 | 1 | 1 | | | 2 | | |
| <i>Dorvillea</i> sp. | | | | | | | | 1 |
| <i>Eteone dilatata</i> | 1 | | | | | | 3 | |
| <i>Eumida bifoliata</i> | 1 | | | | | | 1 | |
| <i>Glycera americana</i> | | | | | | 1 | 1 | |
| <i>Gyptis brevipalpa</i> | 1 | 1 | | 2 | 1 | 4 | 3 | 1 |
| <i>Haploscoloplos elongatus</i> | 5 | | | | | | 1 | |
| <i>Lumbrineris</i> sp. | | | | | | | 2 | |
| <i>Marphysa</i> sp. | | | | | | 2 | | |
| <i>Nephtys cornuta franciscana</i> | 7 | 2 | 1 | 3 | 4 | | 6 | 2 |
| <i>Nereis procera</i> | 1 | | | | | 1 | 1 | |
| <i>Onuphid</i> | | | 1 | | | | | |
| <i>Paraprionospio pinnata</i> | 1 | | 1 | 2 | 2 | | 1 | |
| <i>Pectinaria californiensis</i> | 1 | | | 1 | | 2 | | |
| <i>Pista disjuncta</i> | | | | 1 | | | | |
| <i>Polydora ligni</i> | | | | | | 15 | 1 | |
| <i>Polydora limicola</i> | 1 | | | | 4 | | | |
| <i>Prionospio cirrifera</i> | 8 | 6 | 2 | 1 | 8 | 211 | 186 | 65 |
| <i>Prionospio-h-newportensis</i> | | | 1 | | | | 2 | |
| <i>Prionospio pygmaeus</i> | | | | 1 | | 6 | 2 | |
| <i>Pseudopolydora paucibranchiata</i> | | | | | | | 1 | |
| <i>Schistomeringos longicornis</i> | | | 1 | | | | | |
| <i>Sigambra tentaculata</i> | 4 | | 7 | 5 | 3 | 6 | 5 | 2 |
| <i>Spiochaetopterus costarum</i> | | | | | | | 1 | |
| <i>Spiophanes missionensis</i> | 7 | 2 | 1 | | | | 3 | 3 |
| <i>Streblosoma crassibranchia</i> | | | | | 1 | 1 | 2 | |
| <i>Tharyx</i> sp. | 33 | 7 | 1 | 1 | 16 | 5 | 22 | 12 |
| Polychaete unidentified | | 1 | | | | | | |
| Total number of specimens | 344 | 141 | 80 | 50 | 100 | 547 | 1312 | 590 |
| Total number of species | 18 | 10 | 14 | 12 | 10 | 17 | 23 | 10 |
| Average number of specimens | 395.5 | | | | | | | |
| Average number of species | 14.3 | | | | | | | |

Table 4. Number of species and specimens of polychaetous annelids collected from Station 3, Long Beach, California 1976-1978.

| Species | 11/76 | 1/77 | 3/77 | 5/77 | 7/77 | 9/77 | 11/77 | 1/78 |
|------------------------------------|-------|------|------|------|------|------|-------|------|
| <i>Acesta cerrutii</i> | | | | | | 1 | | |
| <i>Amaeana occidentalis</i> | | | | | 3 | 1 | | |
| <i>Ampharete labrops</i> | | 1 | | 1 | 2 | 2 | | |
| <i>Amphicteis scaphobranchiata</i> | | | | | 3 | 1 | 1 | 1 |
| <i>Armandia bioculata</i> | | | | | | 2 | 14 | |
| <i>Capitita ambiseta</i> | 78 | 81 | 24 | 15 | 125 | 79 | 56 | 224 |
| <i>Chaetozone corona</i> | 30 | 37 | 65 | 10 | 10 | | 9 | |
| <i>Chone minuta</i> | | | | | | 3 | | |
| <i>Cossura candida</i> | 254 | 119 | 228 | 94 | 445 | 253 | 428 | 351 |
| <i>Diopatra splendidissima</i> | | 2 | | | | 1 | | |
| <i>Diopatra</i> sp. | | | 1 | | | | | |
| <i>Dorvillea</i> sp. | | | | | 2 | | | |
| <i>Eteone dilatata</i> | | | | | | 2 | 1 | 4 |
| <i>Euchone incolor</i> | | | | | 1 | 1 | | |
| <i>Eumida bifoliata</i> | 4 | | | 1 | | | | |
| <i>Glycera americana</i> | | | | | 3 | 1 | | |
| <i>Glycera</i> sp. | | | 1 | | | | | |
| <i>Goniada brunnea</i> | | | | | 1 | | | |
| <i>Gyptis brevipalpa</i> | | 1 | | | | 1 | 1 | 1 |
| <i>Haploscoloplos elongatus</i> | 1 | 1 | | | 1 | 2 | 1 | |
| <i>Harmothoe imbricata</i> | | | 1 | | | 1 | | |
| <i>Harmothoe priops</i> | | | | | | 1 | | |
| <i>Laonice cirrata</i> | | | | | | | 1 | |
| <i>Lumbrineris</i> sp. | | 1 | 1 | 4 | 12 | 6 | 4 | |
| <i>Maldanid</i> | | | | 1 | 1 | | | |
| <i>Melinna oculata</i> | | | | | 1 | | | |
| <i>Nephtys cornuta franciscana</i> | | 5 | 3 | 3 | 16 | 5 | 4 | 14 |
| <i>Nereis procera</i> | | 3 | 3 | 1 | 5 | 2 | | |
| <i>Nothria elegans</i> | | | | 2 | | | | |
| <i>Paraprionospio pinnata</i> | 1 | 3 | | 1 | | | | |
| <i>Pectinaria californiensis</i> | | | 2 | 3 | 1 | | 3 | 2 |
| <i>Poecilochaetus johnsoni</i> | | | | | 2 | | | |
| <i>Polydora citrona</i> | | | | | 5 | | | |
| <i>Polydora ligni</i> | | | | | | 3 | 4 | |
| <i>Polydora limicola</i> | | | | | | 1 | | |
| <i>Polydora socialis</i> | | | | | | 1 | | |
| <i>Polydora websteri</i> | | | | | 1 | | | |
| <i>Prionospio cirrifer</i> | 1 | 1 | | 4 | 16 | 48 | 13 | 221 |
| <i>Prionospio h-newportensis</i> | | | | | | 1 | 1 | |
| <i>Prionospio pygmaeus</i> | | 2 | | 2 | 1 | 5 | 1 | |
| <i>Sigambra tentaculata</i> | 3 | 2 | 3 | | 2 | 1 | 2 | 9 |

Table 4. (cont.)

| Species | 11/76 | 1/77 | 3/77 | 5/77 | 7/77 | 9/77 | 11/77 | 1/78 |
|-----------------------------------|-------|------|------|------|------|------|-------|------|
| <i>Spiochaetopterus costarum</i> | | 1 | | | 2 | 1 | 1 | |
| <i>Spiophanes bombyx</i> | | | 1 | 1 | | | | |
| <i>Spiophanes missionensis</i> | 3 | 1 | | 2 | 4 | | 3 | 1 |
| <i>Sthenelais tertiaglabra</i> | | | | | 1 | 1 | | |
| <i>Streblosoma crassibranchia</i> | | 3 | 6 | 32 | 43 | 39 | 11 | |
| <i>Tharyx</i> sp. | 14 | 44 | 36 | 48 | 200 | 99 | 35 | 22 |
| Total number of specimens | 389 | 307 | 372 | 221 | 893 | 567 | 591 | 850 |
| Total number of species | 10 | 18 | 13 | 18 | 27 | 30 | 22 | 11 |
| Average number of specimens | 523.8 | | | | | | | |
| Average number of species | 18.6 | | | | | | | |

Table 5. Number of species and specimens of polychaetous annelids collected from Station 4, Long Beach, California 1976-1978.

| Species | 11/76 | 1/77 | 3/77 | 5/77 | 7/77 | 9/77 | 11/77 | 1/78 |
|------------------------------------|-------|------|------|------|------|------|-------|------|
| <i>Acesta catherinae</i> | | | | | 1 | 3 | 1 | |
| <i>Amphicteis scaphobranchiata</i> | | | | | | | 7 | 1 |
| <i>Ancistrosyllis hamata</i> | | | | | | 1 | 3 | |
| <i>Armandia bioculata</i> | | 1 | | 1 | 1 | 1 | | 1 |
| <i>Capitella capitata</i> | 27 | 26 | 2 | 53 | 24 | 137 | 13 | 103 |
| <i>Capitita ambiseta</i> | 6 | 7 | 5 | 2 | | 4 | 4 | |
| <i>Chaetozone corona</i> | | | | | | 1 | | |
| <i>Chone minuta</i> | 278 | 69 | 54 | 114 | 84 | 221 | 60 | 145 |
| <i>Cossura candida</i> | | | 1 | | | | | 1 |
| <i>Diopatra</i> sp. | 5 | | | | | 1 | 1 | 2 |
| <i>Eteone dilatata</i> | | | | | | | | 3 |
| <i>Glycera americana</i> | | | | | | 1 | 1 | |
| <i>Goniada littorea</i> | | | | 1 | | 1 | | 2 |
| <i>Gyptis brevipalpa</i> | | | | 1 | | | 1 | 2 |
| <i>Haploscoloplos elongatus</i> | 2 | 2 | | | | | 1 | |
| <i>Harmothoe priops</i> | 3 | 2 | 5 | 5 | 5 | 2 | 7 | 9 |
| <i>Lumbrineris</i> sp. | | | 3 | 13 | | 1 | | 3 |
| <i>Maldanid</i> | | | | 1 | | | | |
| <i>Nephtys caecoides</i> | 31 | 4 | 1 | 1 | 1 | | 1 | 17 |
| <i>Nephtys cornuta franciscana</i> | 1 | | 4 | 3 | 2 | 1 | 1 | 4 |
| <i>Nereis procera</i> | | | | | | 1 | | |
| <i>Nothria iridescent</i> | 1 | | 2 | 3 | | 1 | 2 | 8 |
| <i>Paraprionospio pinnata</i> | | 1 | | 1 | | 1 | | |
| <i>Pectinaria californiensis</i> | | | | | | 3 | | |
| <i>Polydora ligni</i> | | | | | | 2 | | |
| <i>Polydora socialis</i> | 2 | 3 | 11 | 7 | | 44 | 1 | 19 |
| <i>Prionospio cirrifera</i> | | 1 | | | | | | |
| <i>Prionospio h-newportensis</i> | 1 | | | 2 | 1 | 6 | 3 | 4 |
| <i>Prionospio pygmaeus</i> | 6 | | 1 | | 1 | 1 | 1 | |
| <i>Sigambra tentaculata</i> | | | | 3 | | | | |
| <i>Spiochaetopterus costarum</i> | | | | | | 1 | | |
| <i>Spiophanes bombyx</i> | | 27 | 2 | 1 | 2 | | 2 | 1 |
| <i>Spiophanes missionensis</i> | | | 1 | | | | | |
| <i>Sthenelais verruculosa</i> | | | 1 | | | | | |
| <i>Sthenelanelia uniformis</i> | | | 9 | 1 | 2 | 2 | 19 | 12 |
| <i>Streblosoma crassibranchia</i> | | | 1 | | 3 | 2 | | 12 |
| <i>Tauberia oculata</i> | 48 | 10 | 64 | 68 | 37 | 62 | 56 | 65 |
| <i>Tharyx</i> sp. | | | | | | | | |
| Total number of specimens | 408 | 151 | 160 | 262 | 159 | 498 | 173 | 406 |
| Total number of species | 13 | 12 | 17 | 19 | 13 | 26 | 20 | 20 |
| Average number of specimens | 277.1 | | | | | | | |
| Average number of species | 17.5 | | | | | | | |

Table 6. Number of species and specimens of polychaetous annelids collected from Station 5, Long Beach, California 1977-1978.

| Species | 1/77 | 3/77 | 5/77 | 7/77 | 9/77 | 11/77 | 1/78 |
|------------------------------------|-------|------|------|------|------|-------|------|
| <i>Amaeana occidentalis</i> | | | | | | 1 | 2 |
| <i>Amphicteis scaphobranchiata</i> | | | | 5 | | | |
| <i>Armandia bioculata</i> | | | | | | 2 | |
| <i>Capitella capitata</i> | | | 4 | | | | |
| <i>Capitita ambiseta</i> | 7 | 19 | 1 | 28 | 23 | 62 | 16 |
| <i>Chaetozone corona</i> | | 5 | 3 | 2 | | | 22 |
| <i>Cossura candida</i> | 16 | 9 | | 16 | 14 | 46 | 14 |
| <i>Diopatra splendidissima</i> | 1 | | | | | | |
| <i>Diopatra</i> sp. | | | | | | | 1 |
| <i>Dorvillea</i> sp. | | | | 2 | 1 | | |
| <i>Eteone dilatata</i> | | | | | | 4 | 1 |
| <i>Euchone incolor</i> | | | | 2 | | | |
| <i>Eusyllis transecta</i> | 1 | | | | | | |
| <i>Glycera</i> sp. | | 1 | | | | | |
| <i>Gyptis brevipalpa</i> | | 1 | 2 | 2 | | 1 | 1 |
| <i>Haploscoloplos elongatus</i> | 1 | 6 | | 7 | 5 | | 4 |
| <i>Harmothoe imbricata</i> | 1 | 1 | | | | | |
| <i>Lumbrineris</i> sp. | | | 2 | | | | |
| Maldanid | | | | | 1 | | |
| <i>Nephtys cornuta franciscana</i> | 2 | 3 | 14 | 23 | 4 | 28 | 49 |
| <i>Nereis procera</i> | | 1 | | | 1 | | |
| Onuphid | 1 | | | | | | |
| <i>Paraprionospio pinnata</i> | 1 | 3 | 3 | | | | 2 |
| <i>Pectinaria californiensis</i> | | 1 | | | 3 | 1 | |
| <i>Poecilochaetus johnsoni</i> | | 3 | | | | | |
| <i>Polydora</i> sp. | 1 | | | | | | |
| <i>Prionospio cirrifera</i> | | 2 | 2 | 10 | 5 | 121 | 11 |
| <i>Prionospio pygmaeus</i> | | | | | | 1 | |
| <i>Sigambra tentaculata</i> | 2 | 2 | 3 | 13 | 15 | 59 | 23 |
| <i>Spiochaetopterus costarum</i> | | | 3 | | | | |
| <i>Spiophanes berkeleyorum</i> | | 1 | | | | 1 | |
| <i>Spiophanes missionensis</i> | | 1 | | | | | |
| <i>Streblosoma crassibranchia</i> | 12 | 6 | | | 1 | 4 | |
| <i>Tauberia oculata</i> | | | | | | 2 | |
| <i>Tharyx</i> sp. | 3 | 7 | 7 | 29 | 4 | 26 | 39 |
| Polychaete unidentified | | | | 2 | | | |
| Total number of specimens | 47 | 71 | 210 | 132 | 79 | 364 | 184 |
| Total number of species | 13 | 18 | 11 | 13 | 12 | 15 | 13 |
| Average number of specimens | 155.3 | | | | | | |
| Average number of species | 13.6 | | | | | | |

Table 7. Number of species and specimens of polychaetous annelids collected from Station 6, Long Beach, California 1976-1978.

| Species | 11/76 | 1/77 | 3/77 | 5/77 | 7/77 | 9/77 | 11/77 | 1/78 |
|------------------------------------|-------|------|------|------|------|------|-------|------|
| <i>Acesta catherinae</i> | | | | | | | | 1 |
| <i>Amaeana occidentalis</i> | | | | | 3 | 10 | 4 | |
| <i>Ampharete labrops</i> | | | 2 | | | | | |
| <i>Ampharetid</i> | | | | 1 | | | | |
| <i>Amphicteis scaphobranchiata</i> | | | | | 1 | 2 | | |
| <i>Amphicteis</i> sp. | 2 | | | | | | | |
| <i>Anaitides longipes</i> | | | | | | | | 1 |
| <i>Anaitides</i> sp. | | | | | | 1 | | |
| <i>Anaitides williamsi</i> | 2 | | 1 | | | 1 | 2 | 2 |
| <i>Boccardia basilaria</i> | | | | 2 | | | | |
| <i>Capitella capitata</i> | | 3 | | 1 | 1 | | | |
| <i>Capitita ambiseta</i> | 33 | | 5 | 38 | 110 | 84 | 37 | 31 |
| <i>Chaetozone corona</i> | 7 | | 2 | 1 | 2 | | 4 | 2 |
| <i>Chone minuta</i> | | | | | | 1 | | |
| <i>Chone mollis</i> | 2 | | | | | | | |
| <i>Cossura candida</i> | 100 | 6 | 4 | 10 | 11 | 18 | 23 | 1 |
| <i>Diopatra splendidissima</i> | 1 | | | | | | | |
| <i>Dorvillea</i> sp. | | | | | 1 | | | |
| <i>Drilonereis faloata</i> | 1 | 1 | | | | | | |
| <i>Drilonereis filium</i> | | | 1 | | | | | |
| <i>Eteone dilatata</i> | 2 | | | | | 2 | 2 | 4 |
| <i>Euchone incolor</i> | | | 2 | | | | | |
| <i>Exogone gemmifera</i> | 1 | | | | | | | |
| <i>Exogone lourei</i> | | | | | | 1 | | |
| <i>Glycera americana</i> | | | | | | | 2 | |
| <i>Glycera tessellata</i> | | 1 | | | | | | |
| <i>Glycera</i> sp. | | | 1 | | | | | |
| <i>Glycinde armigera</i> | | | | | | 1 | | |
| <i>Goniada littorea</i> | | | | | | | | 2 |
| <i>Gyptis brevipalpa</i> | | | | | 1 | 5 | | 1 |
| <i>Haploscoloplos elongatus</i> | 10 | | 5 | 1 | 4 | 5 | 18 | 13 |
| <i>Harmothoe crassiacirrata</i> | | | | | | | | 1 |
| <i>Harmothoe imbricata</i> | | 1 | 1 | | 1 | | | |
| <i>Harmothoe lunulata</i> | 1 | | | | | | | |
| <i>Laonice cirrata</i> | 1 | | 1 | | 1 | | 1 | 2 |
| <i>Lumbrineris</i> sp. | 3 | | 9 | 9 | 15 | 8 | 5 | 8 |
| <i>Maldanid</i> | 6 | 7 | 7 | 4 | 10 | 5 | 2 | |
| <i>Marphysa belli oculata</i> | | | | | | 2 | | |
| <i>Marphysa disjuncta</i> | | | | | 1 | | | |
| <i>Melinna oculata</i> | | | | | | | 1 | |
| <i>Nephtys cornuta franciscana</i> | 48 | 2 | 2 | 1 | 11 | 18 | 30 | 3 |
| <i>Nereis procera</i> | 7 | | 3 | 2 | 1 | 2 | 2 | 4 |
| <i>Nothria pallida</i> | | | | 1 | | | | |
| <i>Nothria</i> sp. | | | | | | 1 | | |

Table 7. (cont.)

| Species | 11/76 | 1/77 | 3/77 | 5/77 | 7/77 | 9/77 | 11/77 | 1/78 |
|-----------------------------------|-------|------|------|------|------|------|-------|------|
| <i>Paraprionospio pinnata</i> | 1 | 1 | 1 | 3 | 1 | | | 3 |
| <i>Pectinaria californiensis</i> | | | | 2 | 2 | | 1 | |
| <i>Pilargis berkeleyi</i> | | | | 1 | | | | |
| <i>Pista cristata</i> | | | | 2 | | | | |
| <i>Poecilochaetus johnsoni</i> | | | 2 | | | | | 1 |
| <i>Polydora caulleryi</i> | | | | | 1 | | | |
| <i>Polydora citrona</i> | | | | | 4 | | | |
| <i>Prionospio cirrifera</i> | 2 | | | | 1 | 6 | 17 | 8 |
| <i>Prionospio pygmaeus</i> | | 1 | | 1 | 9 | | 2 | 2 |
| <i>Prionospio</i> sp. | | | | | 1 | | | |
| <i>Scalibregma inflatum</i> | | | | | | 1 | | |
| <i>Sigambra tentaculata</i> | 1 | | | 2 | 1 | 7 | 22 | |
| <i>Spiochaetopterus costarum</i> | 1 | | | 5 | 3 | | | |
| <i>Spiophanes berkeleyorum</i> | | | 1 | | | | | |
| <i>Spiophanes bombyx</i> | | | | | | 1 | | |
| <i>Spiophanes missionensis</i> | 3 | 2 | 1 | 1 | 1 | | | 1 |
| <i>Sthenelamella uniformis</i> | | | | | | | 1 | |
| <i>Streblosoma crassibranchia</i> | 15 | 10 | 4 | 6 | 3 | 14 | 4 | |
| <i>Tauberia oculata</i> | 15 | 2 | 4 | 10 | 43 | 12 | | 8 |
| <i>Tharyx</i> sp. | 68 | 27 | 16 | 19 | 49 | 43 | 14 | |
| Total number of specimens | 324 | 56 | 59 | 110 | 268 | 236 | 190 | 91 |
| Total number of species | 25 | 13 | 22 | 23 | 29 | 25 | 21 | 20 |
| Average number of specimens | 166.8 | | | | | | | |
| Average number of species | 21.0 | | | | | | | |

Table 8. Salinity values for various stations in Long Beach, November 1976 through January 1978*.

| Date | Station | | | | | |
|-------|---------|-------|-------|-------|-------|-------|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 11/76 | 33.20 | 33.30 | 33.20 | 33.20 | 33.00 | 33.30 |
| 1/77* | - | - | - | - | - | - |
| 3/77 | 32.30 | 32.20 | 32.35 | 32.20 | 32.20 | 32.23 |
| 5/77 | 32.32 | 32.92 | 33.27 | 32.49 | 32.92 | 33.53 |
| 7/77* | - | - | - | - | - | - |
| 9/77 | 32.55 | 32.75 | 32.63 | 32.92 | 32.98 | 32.84 |
| 11/77 | 32.84 | 32.67 | 33.18 | 33.01 | 32.84 | 32.84 |
| 1/78 | 30.02 | 32.55 | 32.75 | 32.49 | 32.92 | 32.84 |

* Data missing.

Table 9. Precipitation in Long Beach, California, October 1976 through January 1978*.

| Date | Amount of Rainfall (cm) |
|--------------|-------------------------|
| October 1976 | 0.18 |
| November | 0.61 |
| December | 3.66 |
| January 1977 | 4.57 |
| February | 0.89 |
| March | 3.43 |
| April | T |
| May | 5.89 |
| June | T |
| July | 0.0 |
| August | 5.16 |
| September | 0.005 |
| October | T |
| November | T |
| December | 7.70 |
| January 1978 | 19.35 |

*Data from U.S. Weather Bureau, Climatological Data, California, 1976, 1977, 1978.

Table 10. Correlation Coefficients (r) of Rainfall and Species Diversity (H') for Various Stations in Long Beach, November 1976 through January 1978.

| Station Number | r | m (slope) | b (y-intercept) |
|----------------|---------|-----------|-----------------|
| 1 | -0.627* | -0.1 | 0.52 |
| 2 | -0.126 | -0.017 | 1.38 |
| 3 | 0.283 | 0.040 | 1.37 |
| 4 | 0.449 | 0.05 | 1.45 |
| 5 | 0.233 | 0.02 | 1.97 |
| 6 | 0.483 | 0.065 | 2.06 |

* Significant Correlation.

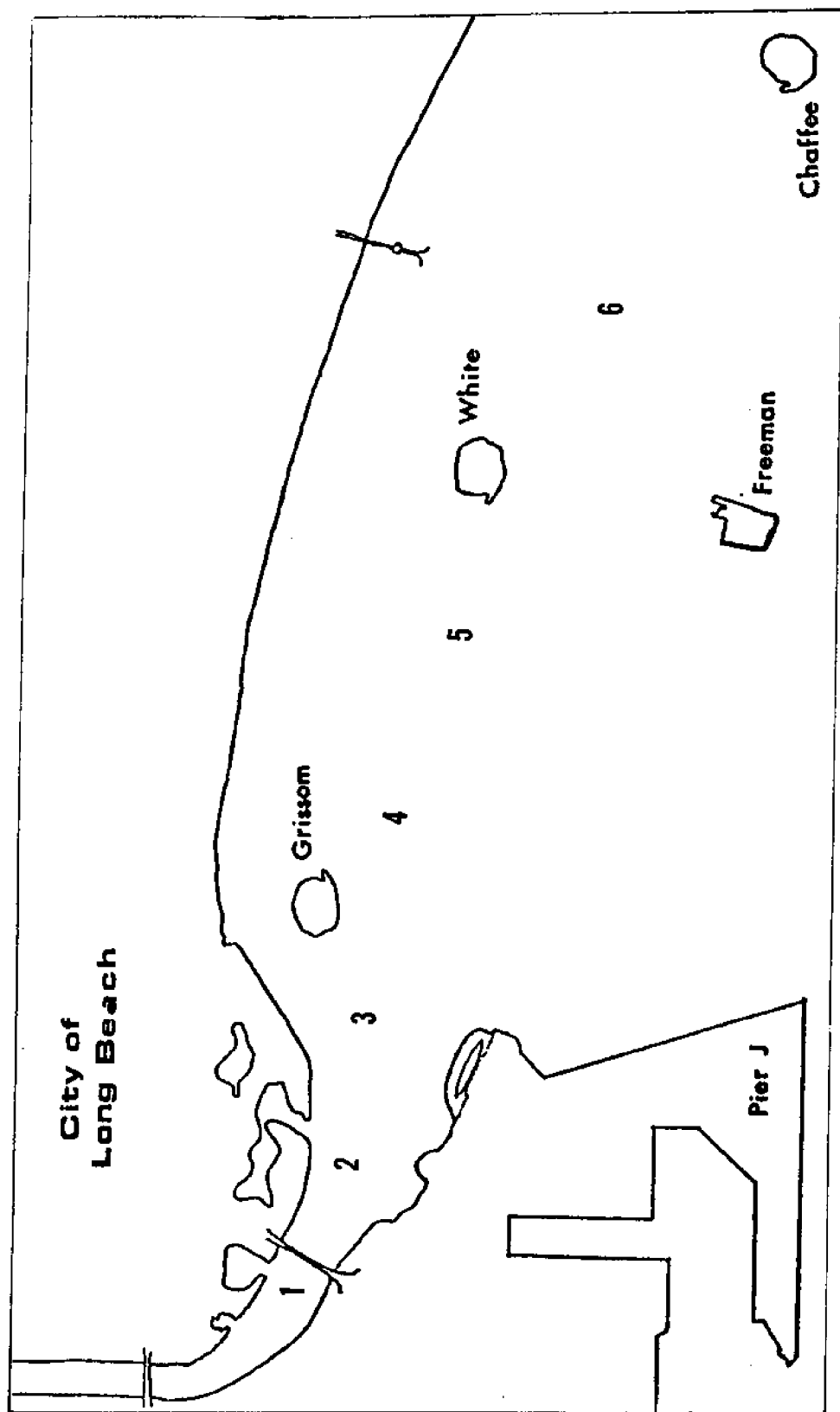


Figure 1. Station locations in Long Beach, sampled between November 1976 and January 1978.

COMPUTER ANALYSIS OF THE BENTHIC FAUNA
AT THE LOS ANGELES RIVER-LONG BEACH HARBOR
COMPARED WITH THE PORTS OF LOS ANGELES AND LONG BEACH

by

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ABSTRACT. Discriminant analysis of benthic data in Long Beach Harbor demonstrated that the community at the mouth of the Los Angeles River related to nearby marine sites in the "dry" summer season but was separated in the winter "wet" season. Computer groupings showed strong relationships with depth and temperature. Seasonal shifts in site groupings and species were shown when data for the entire harbor complex were analyzed with the Long Beach data. One harbor station, farthest from the Los Angeles River and with better oceanic circulation, was biologically quite different, but also was seasonally varied. "Indicator" species groups were thus not as stable as might be expected.

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INTRODUCTION

Engineering activities in or near coastal areas often involve temporary or permanent changes in deposition of marine sediments and, hence, the nature of the bottom (Soule and Oguri, 1976; Sherk, 1971). Operations which disrupt the bottom drastically affect the virtually non-mobile benthic assemblages. The nekton and highly motile epibenthic fauna can avoid an affected area, returning when conditions normalize. The majority of the benthic species, however, are unable to escape and must endure the environmental insult or perish (AHF, 1976).

The Los Angeles-Long Beach Harbor port complex has been the site of extensive construction activities, and proposed future construction will change the geography of the entire area. The ability to predict the effect which any activity will have on the environment is contingent upon the availability of data collected prior to the proposed alterations. Fortunately, the results of several benthic studies of the Los Angeles-Long Beach Harbor are available (AHF, 1976a, 1976b; EQA/MBC, 1975; Hill, 1974; Hill and Reish, 1975; MBC, 1975; Reish, 1959; Reish and James, 1978). Previously, no benthic studies have been published on the data collected by Harbors Environmental Projects in the area of the harbor immediately east of the port complexes. It is therefore the purpose of this report to characterize this area biologically and to compare it with results of studies of the Port areas of Los Angeles-Long Beach Harbors addressed previously (AHF, 1976a).

MATERIALS AND METHODS

Biological and hydrological samples were taken in 1973-1975 at nine sites in the Long Beach City Harbor area (Figure 1). Relatively complete biological data were available for the period March, 1973 - February, 1975. This report, however, deals with single biological samples taken at each station in August and November, 1973, and February, May and August, 1974. The collecting techniques and methods of sample analysis have previously been discussed in the U.S. Corps of Engineers Environmental assessment of the adjacent Los Angeles-Long Beach Harbor Districts (AHF, 1976a). Biotic data obtained for the aforementioned report were also available for this study.

Physical-Chemical

Measurements at one meter intervals through depth of salinity, temperature, dissolved oxygen, and pH were taken monthly with Martek remote sensors. Turbidity (expressed as percent transmittance) was measured by Hydroproducts Transmissometer. Only those data collected immediately above the bottom were considered. Data from grain size and sediment chemistry analyses were not considered here.

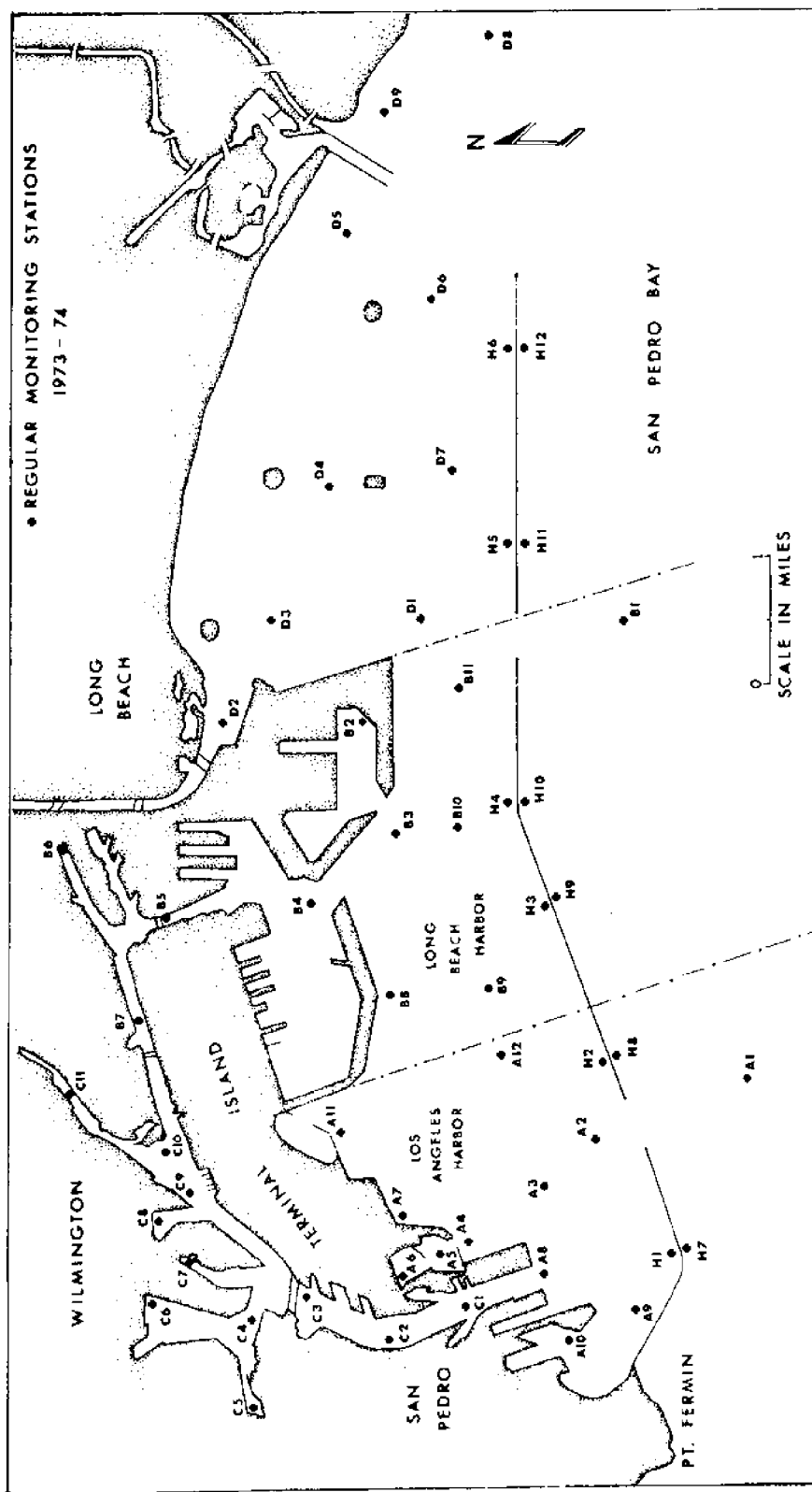


Figure 1. Benthic Monitoring Stations.

Circulation patterns and current measurements of the ports have previously been documented by Soule and Oguri (1972) and Robinson and Porath (1974).

Data Analysis

Classification and multiple discriminant techniques were used to analyze the data. By means of Cluster Analysis, biological data are classified into a number of discrete groups or patterns of co-occurrences (Henry, 1976). The groups delimited by this analysis can then be used in multiple discriminant analysis with the corresponding environmental variables to determine which of the abiotic parameters are strongly correlated with the biotically defined groups (Smith, 1976).

Preliminary analyses of the data from each time period showed that site groupings did not deviate radically throughout the year. The anomalies, however, revealed distinct site groupings for "winter" and "summer" periods. Therefore, the results of the D station analyses presented below represent one summer (August, 1973) and one winter (February, 1974) period. Results of D site discriminant analysis and classification of all the San Pedro Bay sites represent data collected during the same time periods.

Data Reduction

Many species occur so infrequently that they lack a true distribution (Boesch, 1973). It is advantageous to exclude these species from the calculations, thereby reducing the total amount of computing time.

Two factors were considered during data reduction for the present study. Taxa collected at the D sites were not included in calculations if they occurred less than twice during a sampling period, unless their total numbers at the time were greater than ten. During the analysis of all the San Pedro Bay sites, taxa were eliminated from calculations if they occurred less than four times, or if their total numbers were fewer than twenty.

Organisms only identified to taxonomic categories higher than the species level were also discarded unless it was determined that they probably represented a single species. The dimensions of the resulting data matrices utilized in the analysis were:

| <u>No. Entities</u> | <u>No. Attributes</u> | <u>Time Period</u> |
|---------------------|-----------------------|------------------------|
| 8 | 63 | D sites - Aug., 1973 |
| 9 | 63 | D sites - Feb., 1974 |
| 39 | 71 | All sites - Aug., 1973 |
| 43 | 78 | All sites - Feb., 1974 |

The methodology was used for the classification of the sampling sites. Rearrangement of the original matrix with species (attributes) as columns and sites (entities) as rows, transformed by a square-root and standardized by weighted species-maximum (Smith, 1976), resulted in the production of a species dendrogram. Two-Way Tables of coincidence were also produced concurrently with this analysis.

Numerical Classification

The Bray-Curtis coefficient of dissimilarity was used to classify the data. The Bray-Curtis formulation is:

$$D_{ij} = \frac{\sum_{k=1}^n |x_{ki} - x_{kj}|}{\sum_{k=1}^n (x_{ki} + x_{kj})}$$

where D_{ij} is the distance between entities i and j , x_{ki} and x_{kj} are the values of attributes K in i and j , respectively, and n is the number of attributes.

The index is sensitive to the scale of numbers used. Large numbers can influence the numerator of the quotient, but large numbers will receive greater weighting even if those numbers do not result in large differences when the attributes are compared (Smith, 1976). It is therefore desirable to transform, by a log or root, the data to reduce the scale of attribute numbers in such a way that maintains their absolute proportionality.

Any numerical analysis will be adversely influenced by uneven distribution of the attributes. Standardizations help correct this problem. Smith (1976) found that a species-mean standardization following a square-root transformation was efficacious for ecological studies.

The results of the Bray-Curtis formula is a coefficient of dissimilarity ranging from 0 (high similarity) to 1 (high dissimilarity). These were then sorted in a dissimilarity matrix.

A hierarchical clustering strategy, termed Flexible (Lance and Williams, 1967), was utilized to group the entities together and the results were plotted as dendrograms.

Multiple Discriminant Analysis

Smith (1976) extensively reviewed multiple discriminant techniques and should be referred to for a complete explanation of the methodology.

In essence, these techniques can be used to determine the relationships between groups of entities and attributes measured at the entities. Each entity is represented as a point in a multi-dimensional space whose axes are represented by the attributes; the entities will cluster in the dimension(s) where the attributes display minimal variation within the groups (Smith, 1976). Concomitantly, the groups will separate along the dimension(s) where the attributes exhibit a maximal variation between the groups (Smith, 1976). Discriminant scores are then calculated for each entity. These scores are plotted in relation to the relevant axes.

The groups of entities used for discriminant analyses in the present study were delimited by the classification procedure.

Histograms of the attributes (abiotic variables) were examined for any skewness that might be exhibited. These variables would then have to be transformed to make their values more normally distributed. It was deemed, however, that the attributes used in the present study did not significantly deviate from a normal distribution; therefore, transformations were unnecessary.

RESULTS

The overall presentation of results is summarized as follows:

- 1) An overview of the existing biota present at the Long Beach City Harbor sites.
- 2) Exposition of the site and species groups delimited by numerical classification of the aforementioned sites.
- 3) Results of the discriminant techniques used to correlate the biotically defined site groupings with environmental variables.
- 4) The results of the classification of all the sampling sites in the San Pedro Bay vicinity.

Benthos

Approximately 112,500 individuals representing over 280 taxa in 14 invertebrate phyla were obtained from 71 benthic samples collected from Long Beach City Harbor during the entire sampling period in 1973 and 1974. Among the taxa identified to the specific level, 96 were polychaetous annelids and 46 were molluscs. The most abundant organism was the polychaete *Cossura candida* which accounted for nearly 28% of all benthic organisms collected. The ten most abundant species collected, nine of which were polychaetous annelids, accounted for about 79% of the total organisms collected (Table 1). A summary of the biotic data collected at the other San Pedro Bay sites within the Ports of Los Angeles and Long Beach has been reported elsewhere (AHF, 1976a).

Normal Classification - D Sites

The results of normal classification for August, 1973 and February, 1974 are presented in Figures 2 and 3, respectively. Maps of the sites are presented in Figures 4 and 5. Four site groups, of which two were composed of single stations, are delimited for the August, 1973 period, and three distinct site groups are produced for the February, 1974 period. The only difference between the two dendrograms is the placement of site D2 in relation to site D3. The February, 1974 analysis groups these two sites together, but the August, 1973 analysis separates them.

Inverse Classification - D Sites

The species-group dendrograms for August, 1973 and February, 1974, are presented in Figures 6 and 7, respectively. The two-way tables of coincidence (TWT) for these groups are presented in Tables 2 and 3, respectively.

Five species groups are delineated by the analysis for both periods. Several differences are apparent between the two classifications. The composition of the species groups which the analysis delineated as being indicative of the site groups show marked change during the two periods. One example of this is the species groups indicative of sites D5 and D8 in August, 1973 and D5, D8 and D9 in February, 1974. A total of 20 taxa are listed as constituents of these groups (Group V - August, 1973 and Group III - February, 1974), of which only the two species of polychaetous annelids *Chaetozone setosa* and *Prionospio pygmaeus* are common to both groups. This seasonality is apparent in most of the species groups.

Another interesting phenomenon revealed by the classification is the apparent biotic "uniqueness" of site D6. This can readily be seen in the Two-way Tables (Tables 2, 3) of both periods, in which species group I (of both months) is very indicative of site D6. This is especially so for August, 1973. It should also be noted that the composition of these groups is also quite different from month to month.

Multiple Discriminant Analysis - D Sites

The plots of multiple discriminant scores for August, 1973 and February, 1974 are presented in Figures 8 and 9. The site groups delineated by classification are well separated by projection of the first two axes in both cases. The August analysis indicates that Axis I is primarily a function of pH, with temperature being only secondarily related to the axes. Axis I of February, 1974 is primarily a function of temperature. It should be noted, however, that pH was not a variable under consideration during the calculations of discriminant scores for February, 1974.

Axis II is primarily a function of depth in the August, 1973, plot, while it is most strongly correlated with mean DO in the February, 1974 plot, whereas depth and turbidity (% transmission) were only secondarily related.

Normal Classification - All Sites

The site group dendrograms of all the San Pedro Bay sites for August, 1973 and February, 1974 are presented in Figures 10 and 11, respectively. Five site groups are discernible for each period. One of the most interesting things to note is the segregation of the mid-bay group of D sites during August, 1973 (Figure 12). This same group of sites is not clearly separated during February, 1974, reflecting the rainy season runoff (Figure 13). Except for a few discrepancies, clear groupings of outer and inner harbor and back bay sites are evident for both sampling periods examined.

Inverse Classification - All Sites

The species group dendrograms for August, 1973 and February, 1974 are presented in Figures 14 and 15, respectively. Two-way tables for each period are presented in Tables 4 and 5, respectively. Seven species groups are delimited for each period. In general, these species groups exhibit less seasonality than those groups revealed by the analysis of the D sites. For example, site groups I (August, 1973) and IV (February, 1974), which might be called the outer harbor sites, are represented by species groups III and V from the same months, respectively. Examination of these groups shows that many of the constituents are common to both.

DISCUSSION

One of the primary purposes of this study was to contrast the biotically defined environmental gradients at the D stations with the other sites in San Pedro Bay. The D stations are somewhat unique among all the sampling sites in the bay since the area lacks the commercial ship traffic that the other areas of San Pedro Bay are subjected to, it is a site of petroleum production, and it receives vast amounts of freshwater input from the Los Angeles River and also the San Gabriel River.

Seasonal changes in the constituents of the site groups clusters are minor but possibly highly revealing of the stress factors influencing the area. Site D2 forms a single station group during the summer period, but is grouped with site D3 during the winter. This may be due in part to large salinity changes during winter runoff, but possibly also to amounts of chemical and thermal pollutants entering the bay system at D2 (AHF, 1976) coupled with the shallowness of the site.

Discriminant analysis reveals strong site relationships with both depth and temperature. Unfortunately, sediment chemistry and grain size data were not available. It would intuitively seem likely that these data would heavily influence any analysis of the area.

Another interesting phenomenon revealed by the analysis is the fairly "unique" nature of site D6. Site D6 appears to support two biotas, its own

and the one it shares with sites D1, D4, and D7. The reason for this is unknown. Small changes in the sediment composition might lead to this condition. D6 is also subjected to greater flushing due to its close proximity to the end of the breakwater.

The seasonal changes in the composition of the site groups throughout the entire harbor delimited by classification can readily be seen upon inspection of Figures 12 and 13. The February, 1974 analysis groups the majority of the D stations with most of the stations that comprised the site group V reported by AHF, 1976. This grouping does not exist during August, 1973. This appears particularly significant if one considers rainfall patterns and location of outfalls on the eastern portion of Terminal Island. February, 1974 data were collected during a relatively rainy period, a period when flushing of outfall sites is probably maximal. This is in contrast to the August, 1973 summer period when flushing would be minimal. This tends to suggest that the AHF (1976) site group V is actually an area that displays seasonal stress, and will not be a stable grouping, but may merge with group W.

The site groups reported in AHF (1976) as W and X, when compared to the groupings found in August, 1973 (W'-X') and February, 1974 (W''-X'') are fairly stable. It appears that whatever stress or natural variables these groups are subjected to are uniform throughout the year.

The stability of groups Y and Z (AHF, 1976) is not maintained when the D station analyses are included. Most of the original group Y and Z stations are combined as site groups Y' (August, 1973) and Y'' (February, 1974). It is unclear why this discrepancy should exist between the results of the present study and those of AHF (1976). This may be due to the fact that the data from March and November, 1973 were not analyzed for the present study, or that inclusion of some D station data altered the correlation coefficients.

Table 6 is a listing of organisms indicative of areas of the harbor reported by previous studies and also those groupings delimited by this study. This shows that not only do some site groups change seasonally, but that even species indicative of a relatively stable site change seasonally. Thus, any model using "indicator species" must allow for seasonality.

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Table 1. The Ten Numerically Dominant Species from the D Stations, 1973-1975.

| SPECIES | NUMBER COLLECTED | % of TOTAL |
|------------------------------------|------------------|------------|
| <i>Cossura candida</i> | 31,348 | 27.67. |
| Cirratulidae, <i>Tharyx</i> spp. | 24,239 | 21.55 |
| <i>Capitita ambiseta</i> | 21,353 | 18.98 |
| <i>Prionospio cirrifer</i> | 2,957 | 2.63 |
| <i>Nephtys cornuta franciscana</i> | 2,633 | 2.34 |
| <i>Sigambra tentaculata</i> | 2,102 | 1.87 |
| <i>Chaetozone corona</i> | 1,179 | 1.05 |
| <i>Haploscoloplos elongatus</i> | 1,124 | 1.0 |
| Nemertea, various species | 996 | 0.88 |
| <i>Lumbrineris</i> spp. | 735 | 0.65 |

Table 2. Two-Way Table; August 9, 1973.

| SPECIES | Station Group | D | D | D | D | D | D | D | D |
|---|------------------|---|---|---|---|---|---|---|---|
| | | 1 | 4 | 6 | 7 | 2 | 5 | 8 | 3 |
| <i>Retusidae, Volvullella</i> | I | | | * | | | | | |
| <i>Myrella pedroana</i> | | | | * | | | | | |
| <i>Axinopsida serricata</i> | | - | | * | | | | | |
| <i>Ezogone gemmifera</i> | | + | | * | | | | | |
| <i>Melinna oculata</i> | | * | | * | | | | | |
| <i>Diopatra ornata</i> | | + | | * | | | | | |
| <i>Spirochaetopterus (=Telepsavus)</i> | | - | | * | | | | | - |
| <i>Boccardia basilaria</i> | | * | | * | - | | | | |
| <i>Lucinidae, Parvilucina</i> | | - | | * | * | | | | |
| <i>Pectinaria californiensis-newpt.</i> | | | | * | - | | | | |
| <i>Notomastus attenuatus</i> | | | | * | + | | | + | |
| <i>Cooperella subdiaphana</i> | | | | * | * | | | - | |
| <i>Terebellidae, Pista</i> | | | | * | | | | | |
| <i>Euchone incolor</i> | | | | * | | | | | |
| <i>Amphiteles scaphobranchiata</i> | | - | | * | | - | | | |
| <i>Pelecypoda, Veneroida</i> | | | | * | | | | | |
| <i>Armandia bioculata</i> | | | | * | | * | | | |
| <i>Pista disjuncta</i> | | | | * | | * | | | |
| <i>Haploscoloplos elongatus</i> | II | . | * | * | - | | | - | |
| <i>Ampharete labrops</i> | | - | + | * | - | | | - | |
| <i>Nephtys cornuta-franciscana</i> | | - | * | * | * | | | | |
| <i>Compsomaz subdiaphana</i> | | + | - | * | * | | | | |
| <i>Paraprionospio pinnata</i> | | * | * | * | + | - | | - | + |
| <i>Sigambra tentaculata</i> | | * | + | * | * | * | | | |
| <i>Chaetoxone corona</i> | | + | - | * | * | - | | - | |
| <i>Prionospio cirrifera</i> | | - | + | * | - | * | | * | |
| <i>Spiophanes berkeleyorum</i> | | * | + | + | + | * | | * | |
| <i>Cyrtis brevipalpa</i> | | . | * | + | * | . | | . | |
| <i>Nereis procerus</i> | | * | * | * | * | * | | * | |
| <i>Macoma acicula</i> | | * | * | * | * | + | | * | |
| <i>Laonice cirrata</i> | | - | + | * | * | * | | * | |
| <i>Callinassa sp.</i> | | + | * | * | * | - | | * | |
| <i>Streblosoma crassibranchia</i> | | * | * | * | * | * | | + | |
| <i>Barmothos priops</i> | III | - | * | * | * | - | | * | |
| <i>Cadulus fusiformis</i> | | - | * | * | * | - | | * | |
| <i>Marphysa disjuncta</i> | | + | * | * | * | - | | * | |
| <i>Vitrinella oldroydi</i> | | * | * | * | * | - | | * | |
| <i>Glycera americana</i> | | * | * | * | * | - | | * | |
| <i>Glycera capitata</i> | | * | * | * | * | - | | * | |
| <i>Drilonereis falcata</i> | | * | * | * | * | - | | * | |
| <i>Polydora caulleryi</i> | | - | * | * | * | - | | * | |
| <i>Magelona pacifica</i> | | * | * | * | * | - | | * | |
| <i>Listriolobus pelodes</i> | | + | * | * | * | - | | * | |
| <i>Polydora ligni</i> | IV | - | * | * | * | * | | * | |
| <i>Schistomeringos longicornis</i> | | - | * | * | * | * | | * | |
| <i>Macoma nasuta</i> | | * | + | * | * | * | | * | |
| <i>Cirratulidae, Tharyx</i> | | + | * | * | * | * | | * | |
| <i>Capitula ambigua</i> | | * | * | * | * | * | | * | |
| <i>Cossura candida</i> | | - | * | * | * | * | | * | |
| <i>Paraonis gracilis-oculata</i> | V | | | | | | | * | * |
| <i>Siliqua sp.</i> | | | | | | | | * | * |
| <i>Phoronis sp.</i> | | | | | | | | * | * |
| <i>Amasena occidentalis</i> | | | | | | | | * | * |
| <i>Matridae, Spisula</i> | | | | | | | | * | * |
| <i>Nothria iridescentis</i> | | | | | | | | * | * |
| <i>Spiophanes bombyx</i> | | | | | | | | * | * |
| <i>Magelona pitelkai</i> | | | | | | | | * | * |
| <i>Prionospio pygmaeus</i> | | - | * | + | * | * | | * | * |
| <i>Anatides williamsi</i> | | + | * | * | * | * | | * | * |
| <i>Pista fasciata</i> | | * | * | * | * | * | | * | * |
| <i>Coelenterata, Anthozoa</i> | | | | | | | | * | * |
| <i>Spiophanes missionensis</i> | | - | * | * | * | * | | * | * |
| <i>Chaetoxone setosa</i> | | | | | | | | * | * |

Table 3. Two-Way Table, February, 1974.

| SPECIES | Station Group | D D D D | | | | D D | | D D D | | |
|---|------------------|---------|---|---|---|-----|---|-------|---|---|
| | | 1 | 7 | 4 | 6 | 2 | 3 | 5 | 9 | 8 |
| <i>Exogone gemmifera</i> | I | - | | * | | | | | | |
| <i>Boccardia basilaria</i> | | . | | * | | | | | | |
| <i>Streblosoma crassibranchia</i> | | - | | * | | | | | | |
| <i>Melinna oculata</i> | | - | + | * | | | | | | |
| <i>Pherusa neopapillata</i> | | | + | * | | | | | | |
| <i>Pholoe glabra</i> | | - | * | + | | | | | | |
| <i>Maryphysea disjunata</i> | | + | * | * | - | | | | | |
| <i>Compsomya subdiaphana</i> | | | * | * | * | - | | | | |
| <i>Steona dilatata</i> | | - | * | * | * | | | | | |
| Lucinidae, <i>Parvilocina</i> | | + | * | * | * | | | | | |
| <i>Anatides williamsi</i> | | | | * | * | | | | | - |
| <i>Glycera americana</i> | | - | - | * | * | - | | | | |
| <i>Macoma acolasta</i> | | | | * | * | + | | | | |
| <i>Lucina nuttalli</i> | | | | * | * | | | | | |
| <i>Spiophanes missionensis</i> | | | | * | * | + | - | | | |
| <i>Callianassa</i> sp. | | - | - | - | - | * | | | | |
| <i>Gyptis brunnea</i> | II | * | * | * | * | | | | | |
| <i>Thyasira flexuosa</i> | | * | * | * | * | | | | | |
| <i>Exogone loursi</i> | | + | * | * | * | | | | | |
| <i>Decamastus gracilis</i> | | + | * | * | * | | | | | |
| <i>Phoronis</i> sp. | | | + | * | * | | | | | |
| <i>Prionospio malmgreni</i> | | | * | * | * | | | | | |
| <i>Vitrinella oldroydi</i> | | | * | * | * | | | | | |
| <i>Paraprionospio pinnata</i> | | + | * | * | * | * | - | * | | |
| <i>Ampharete labrops</i> | | - | * | + | + | * | * | * | | |
| <i>Boccardia polybranchia</i> | | * | * | * | * | + | * | * | | |
| <i>Amphiteteis scaphobranchiata</i> | | * | + | + | + | * | * | * | | |
| <i>Spirochaetopterus</i> (= <i>Telepsavus</i>) | | | * | * | * | - | * | * | * | |
| <i>Amasena occidentalis</i> | | + | * | * | * | | | * | * | * |
| Mactridae, <i>Spiacula</i> | | | * | * | * | | | * | * | * |
| <i>Gyptis brevipalpa</i> | | + | * | * | * | - | * | + | - | |
| <i>Notomastus tenuis</i> | | | * | + | + | | | + | | |
| <i>Aricidea vassii</i> | III | | | | | | | - | * | * |
| <i>Tellina modesta</i> | | | | | | | | - | * | * |
| <i>Prionospio pygmaeus</i> | | . | | * | * | | | * | * | * |
| <i>Mediomastus acutus</i> | | | | | | | | * | * | * |
| <i>Diopatra ornata</i> | | + | | | | | | * | * | * |
| <i>Goniada brunnea</i> | | - | | - | | | | * | * | * |
| <i>Magelona pacifica</i> | | - | - | - | | | | * | * | * |
| <i>Chaetoxone setosa</i> | | | | | | | | | * | * |
| Dorvilleidae, <i>Protodorvillea</i> | | | | | | | | | * | * |
| <i>Sigambra tentaculata</i> | IV | * | * | * | * | - | * | | | |
| <i>Nephtys cornuta-franciscoana</i> | | * | * | * | * | - | + | | | |
| <i>Haploscoloplos elongatus</i> | | - | + | * | * | . | . | | | |
| <i>Euchone incolor</i> | | + | + | * | * | . | . | | | |
| <i>Paraonis gracilis-oculata</i> | | * | + | * | * | . | . | | | |
| <i>Chaetoxone corona</i> | | * | * | * | * | . | . | | | |
| Cirratulidae, <i>Tharyx</i> | | * | * | * | * | . | . | | | |
| <i>Capitita ambiseta</i> | | + | + | + | + | * | * | - | + | * |
| <i>Cossura candida</i> | | + | + | . | . | * | * | . | . | . |
| <i>Glycera capitata</i> | V | + | | | | * | * | | | |
| <i>Pectinaria californiensis-newportensis</i> | | * | | | | * | * | | | |
| <i>Barmothos priops</i> | | * | | | | * | * | | | |
| <i>Laonice cirrata</i> | | - | + | * | * | * | * | | | |
| <i>Spiophanes lerkaleyorum</i> | | + | * | * | + | * | * | | | |
| <i>Theora lubrica</i> | | | | | | * | * | | | |
| <i>Heris procera</i> | | + | - | * | * | - | * | | | |
| <i>Prionospio cirrifera</i> | | . | | * | + | * | * | | | |
| <i>Schistomeringos longicornis</i> | | | | * | * | + | * | | | |
| <i>Coopersella subdiaphana</i> | | | | * | * | + | * | | | |
| <i>Capitella capitata</i> | | | | * | * | + | * | | | |
| Polychaeta, <i>Veneroida</i> | | + | + | * | * | * | * | | | |
| <i>Armandia bioculata</i> | | | | * | * | * | * | + | | |

Table 6. "Indicator Organisms Reported from Los Angeles-Long Beach Harbors Groupings Based on Environmental Quality.

Source

| Very Polluted | Polluted | Semi-Healthy II | Semi-Healthy I | Healthy |
|------------------|--|--|---|---|
| Reish, 1959 → | <i>Capitella capitata</i> | <i>Cirriformia lasuriosa</i> | <i>Polydora paucibranchiata</i> <i>Schistomeringos longicornis</i> | <i>Tharyx ? parvus</i> |
| Hill, 1974 → | "Polluted" (station 24) | | | |
| | <i>Capitella capitata</i> <i>Capitella ambiseta</i> <i>Polydora ligni</i> | | | <i>Tharyx parvus</i> <i>Cossura candida</i> <i>Haploscoloplos elongatus</i> |
| AHF, 1976 → | Group 2 | Group Y | Group X | Group W |
| | <i>Capitella capitata</i> <i>Armandia bicaulata</i> <i>Polydora ligni</i> <i>Pseudopolydora paucibranchiata</i> | <i>Schistomeringos long.</i> <i>Capitella capitata</i> <i>Ophiodromus pugetten.</i> <i>Theora lubrica</i> | <i>Euchone limnicola</i> <i>Callianassa sp.</i> <i>Cryptomya calif.</i> <i>Nephtys a. frans.</i> | <i>Tharyx? parvus</i> <i>Cossura cand.</i> <i>Haploscolo.</i> <i>elongatus</i> <i>Priono. pinn.</i> |
| MBC, 1975 → | Group I | | | |
| | <i>Tharyx spp.</i> <i>Cossura candida</i> <i>Capitellidae*</i> <i>Euphilomedes</i> | | | <i>Tharyx spp.</i> <i>Cossura cand.</i> <i>Parconia gra.</i> <i>oculata</i> |
| August, 1973 → | Group Y' | Group S' | Group X' | Group W' |
| | <i>Capitella capitata</i> <i>Polydora ligni</i> <i>Chaetozone setosa</i> | <i>Magelona piteikai</i> <i>Nothria tridescens</i> | <i>Schisto. longi.</i> <i>Macoma nasuta</i> <i>Ophiodromus pugettensis</i> | <i>Cyrtis aren.</i> <i>Cyrtis glabra</i> <i>Amphiteis scaphobran.</i> <i>Glycera amar.</i> |
| February, 1974 → | Group Y'' | Group S'' | Group X'' | Group W'' |
| | <i>Capitella capitata</i> <i>Polydora ligni</i> <i>Schistomeringos longicornis</i> | <i>Aricidea wassii</i> <i>Tellina modesta</i> <i>Mediomastus acutus</i> | <i>Cryptomya calif.</i> <i>Pseudopolydora paucibr.</i> <i>Macoma nasuta</i> | <i>Thyastrea fiez.</i> <i>Myrella pedro.</i> <i>Pectinaria californien.</i> |
| | | | | <i>Nephtys a. fr.</i> <i>Amphiteis scaphobran.</i> <i>Cyrtis brevit.</i> |

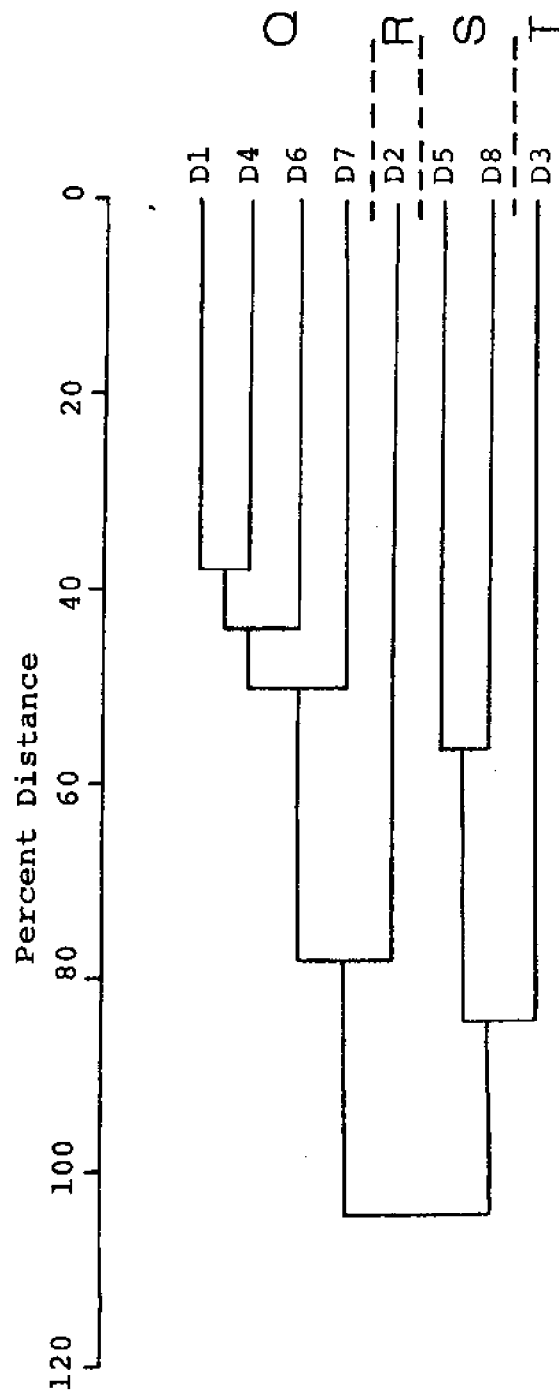


Figure 2. Normal Analysis; August 9, 1973.

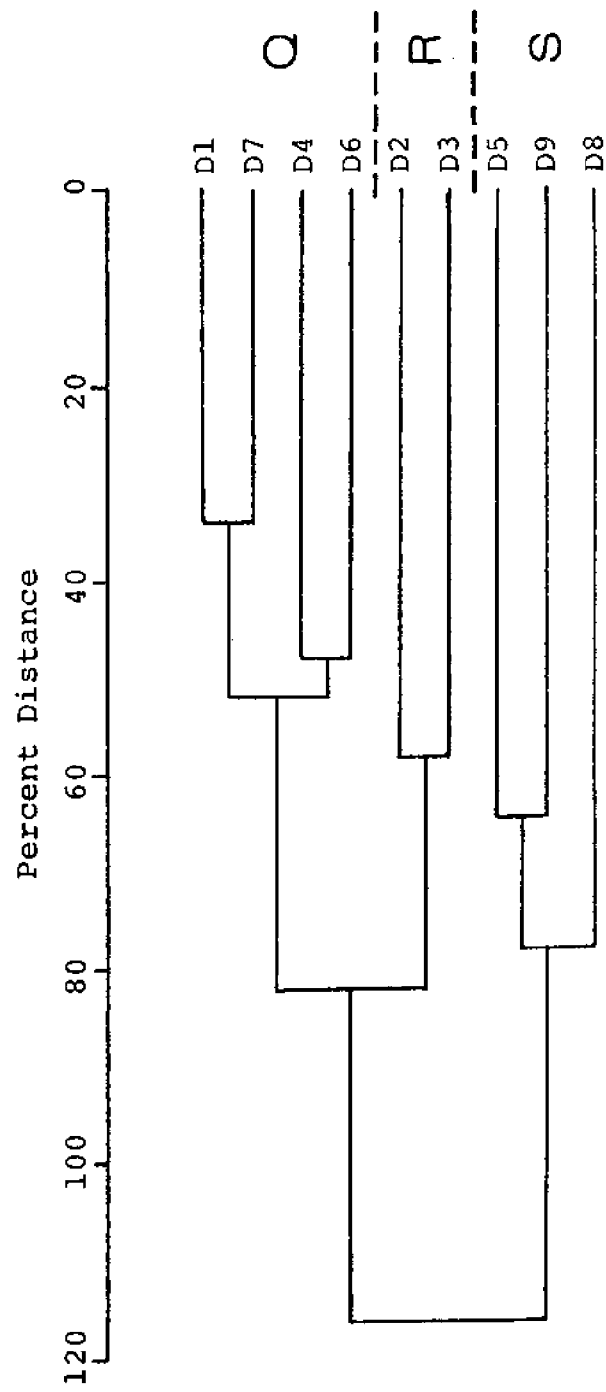


Figure 3. Normal Analysis; February 11, 1974.

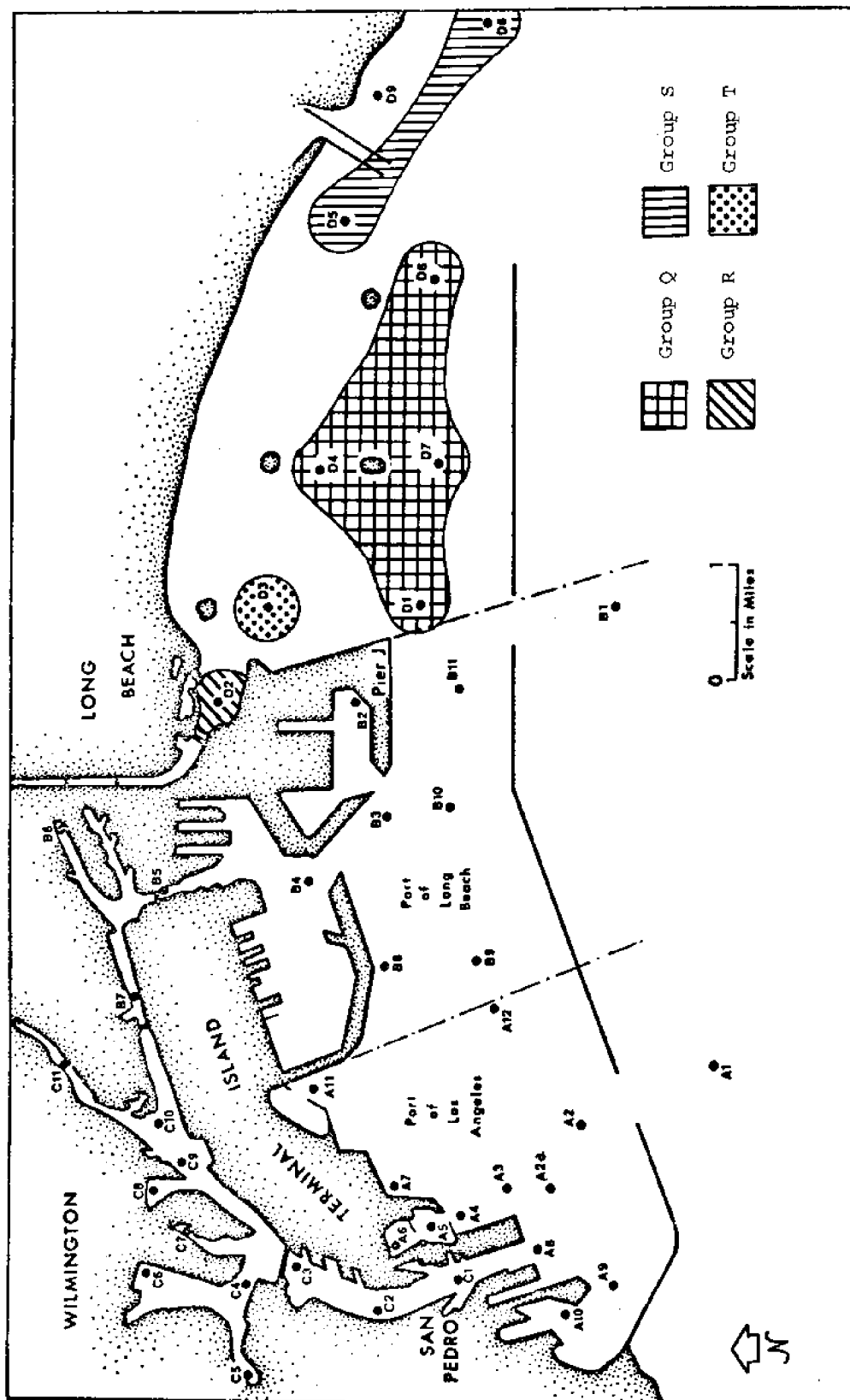


Figure 4. D Station Site Groups. August, 1973.

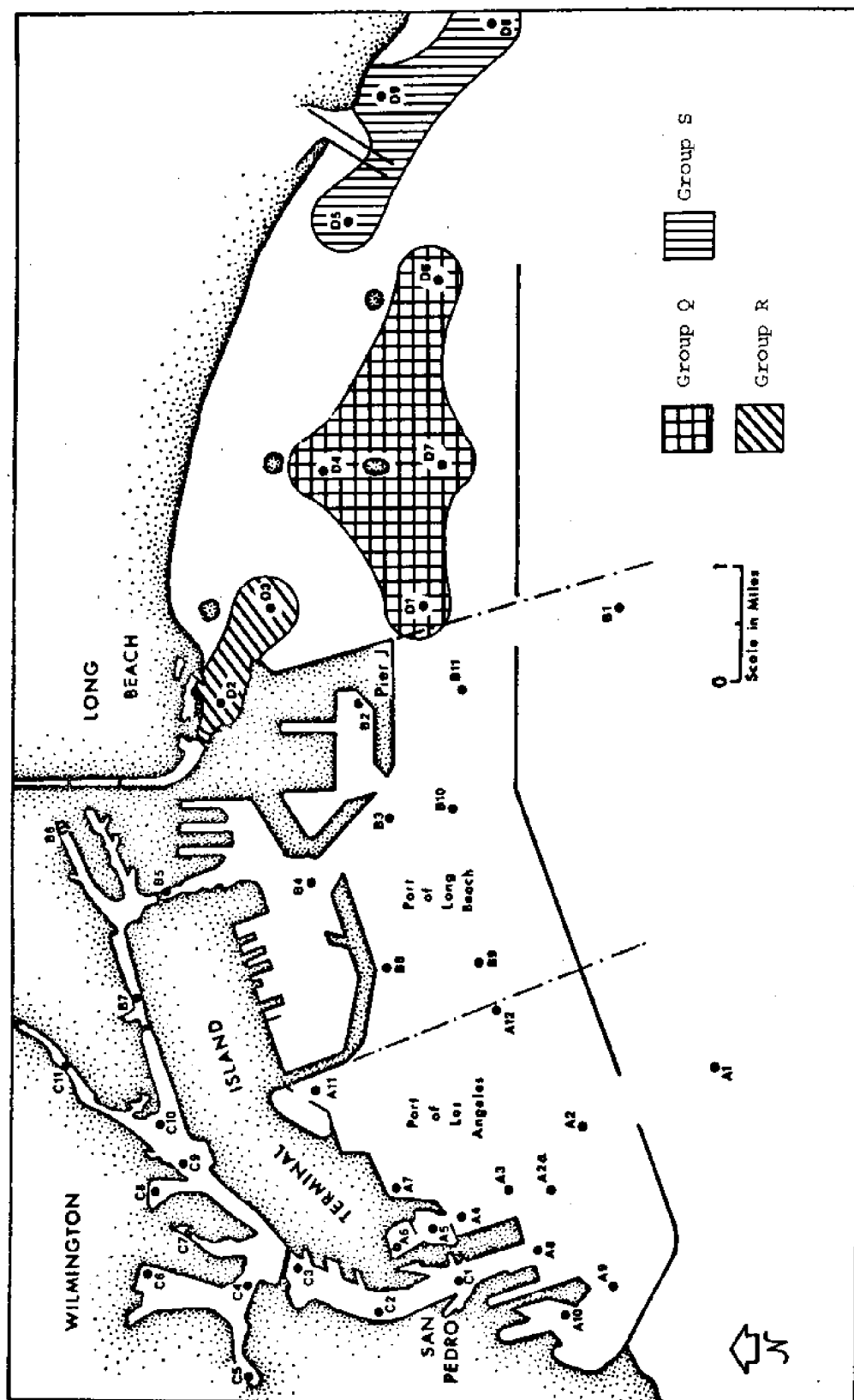


Figure 5. D Station Site Groups. February, 1974.

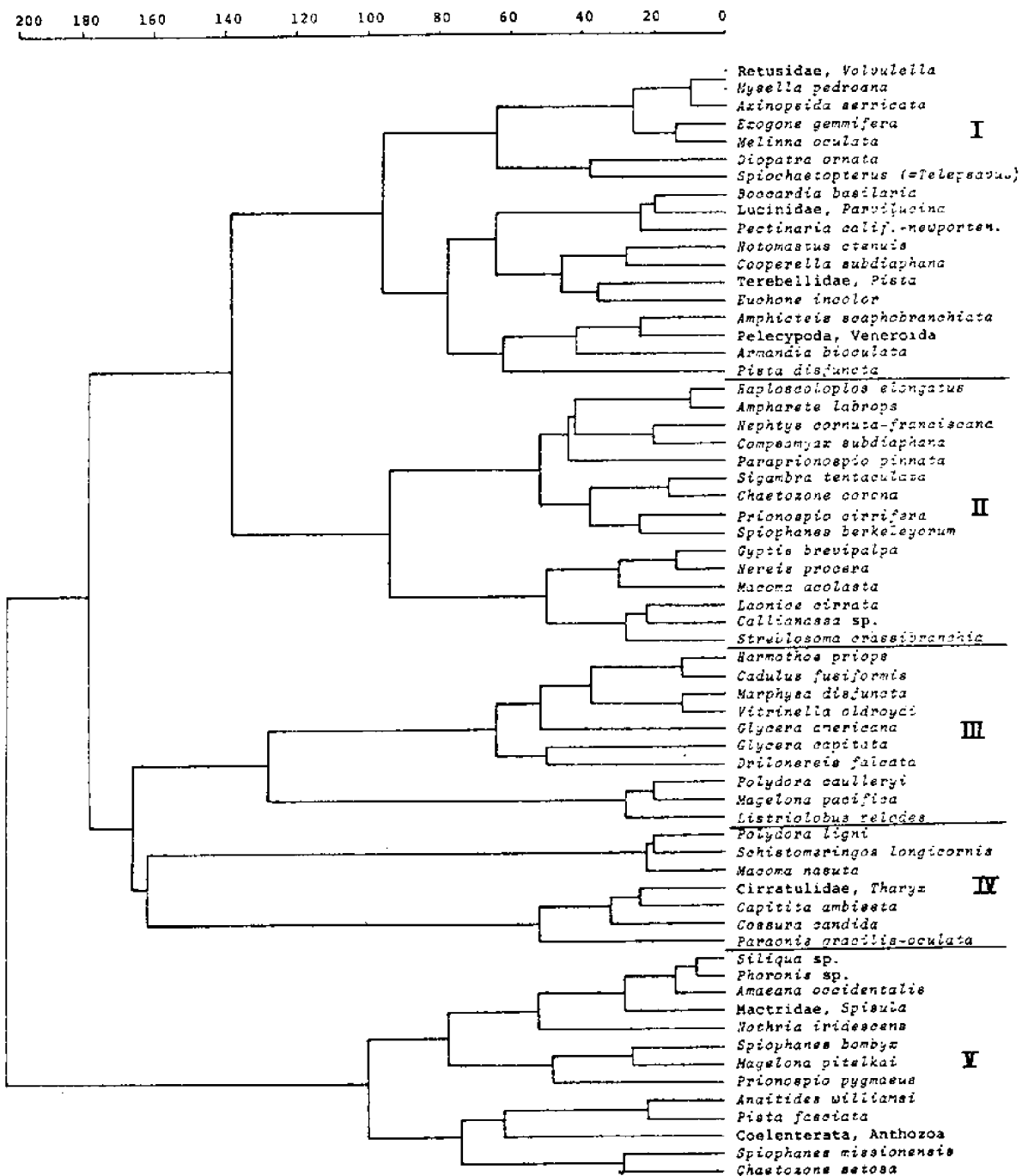


Figure 6. Inverse Classification. August 1973.

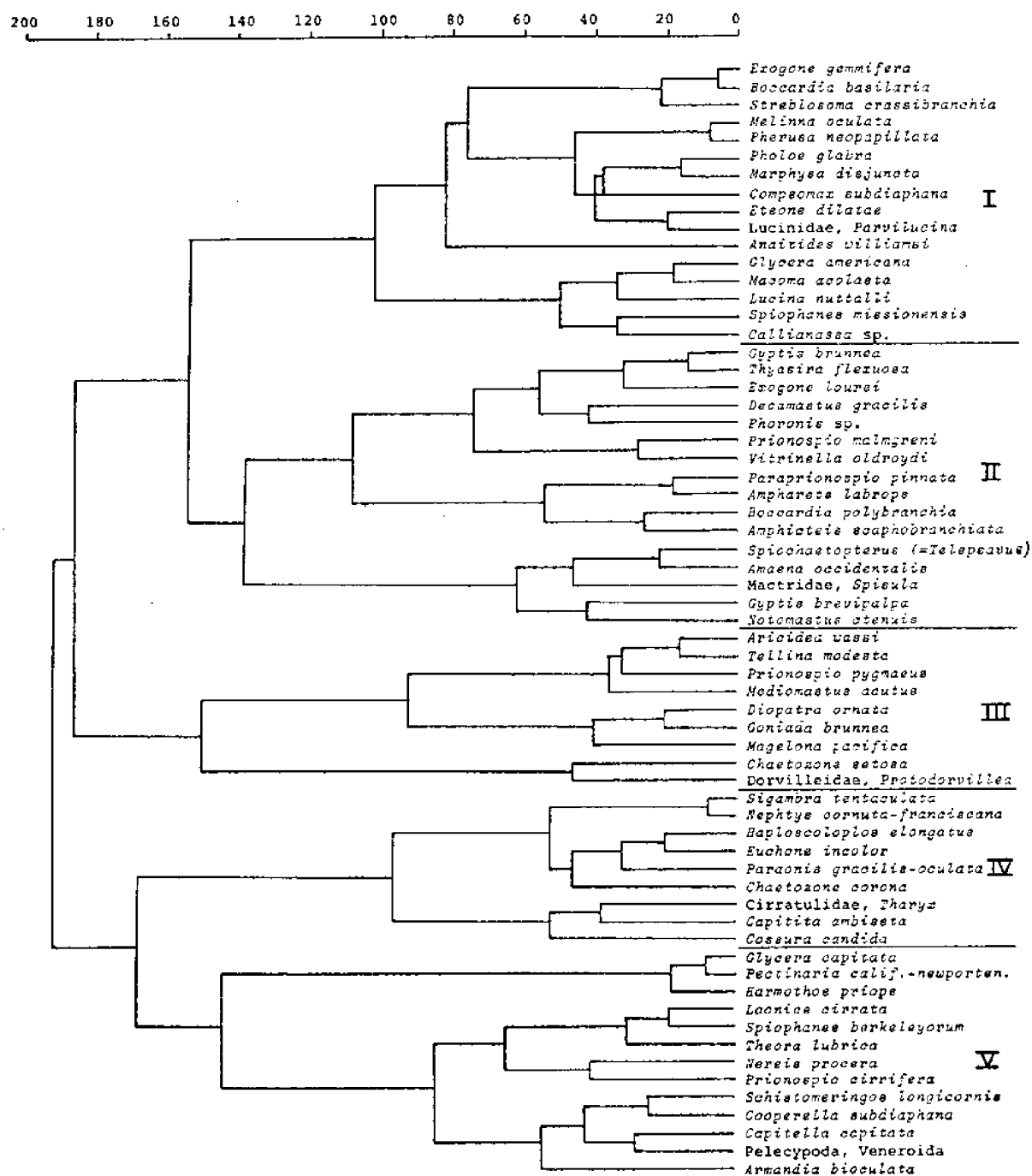


Figure 7. Inverse Classification. February 1974.

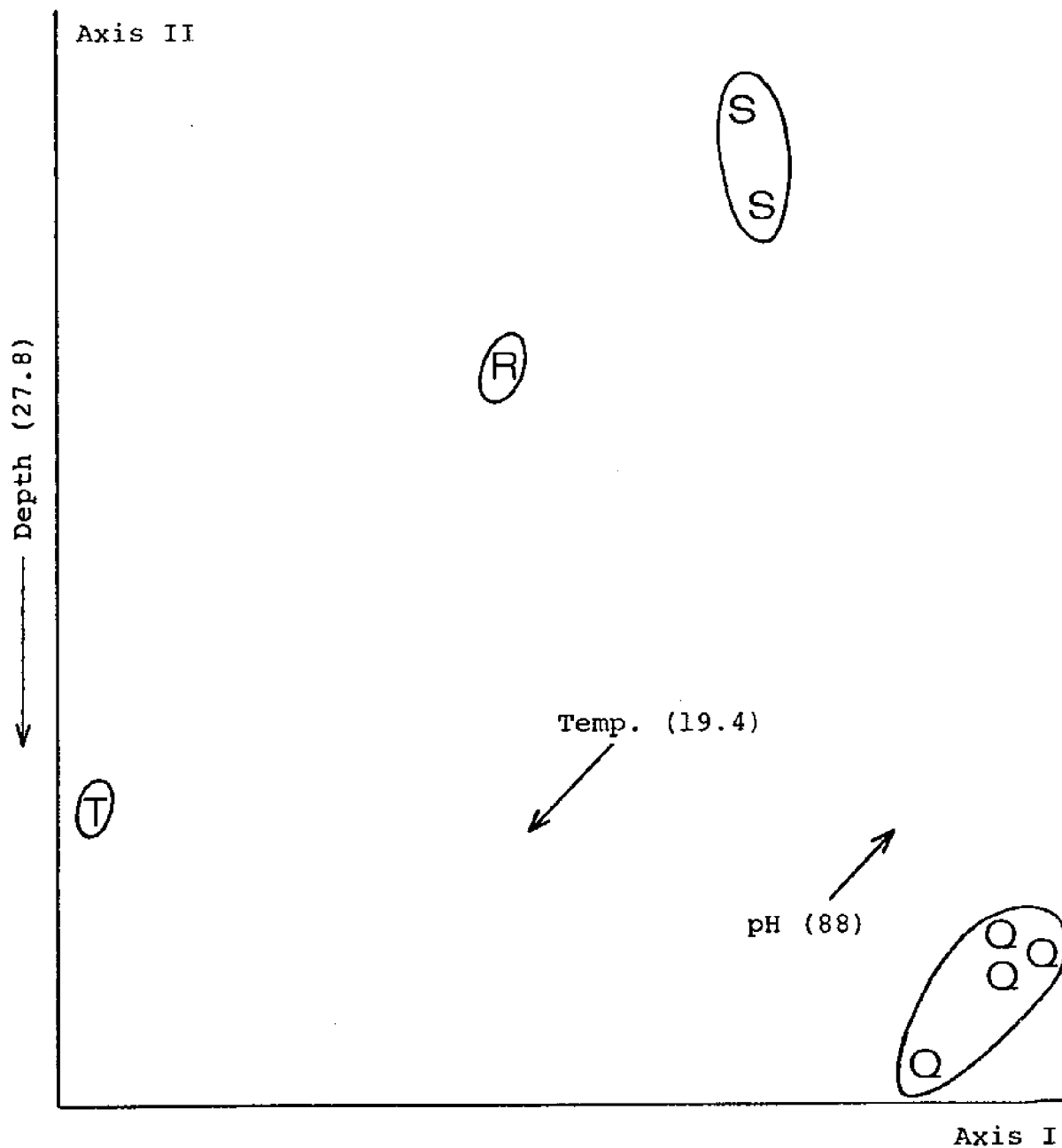


Figure 8. The distribution of D station site groups for August, 1973 in discriminant space. Coefficients of separate determination are in parentheses.

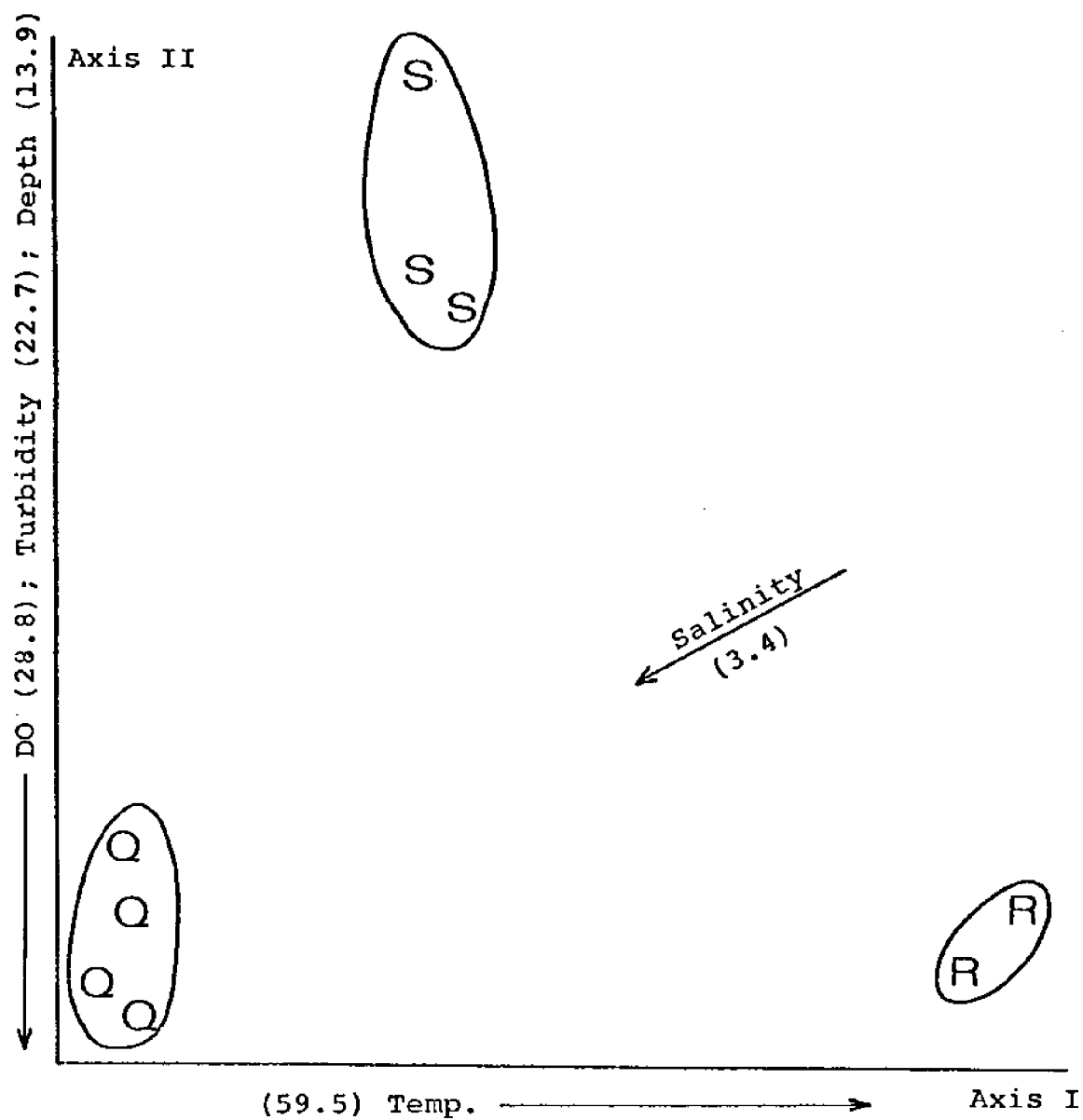


Figure 9. The distribution of D station site groups for February, 1974, in discriminant space. Coefficients of separate determination are in parentheses.

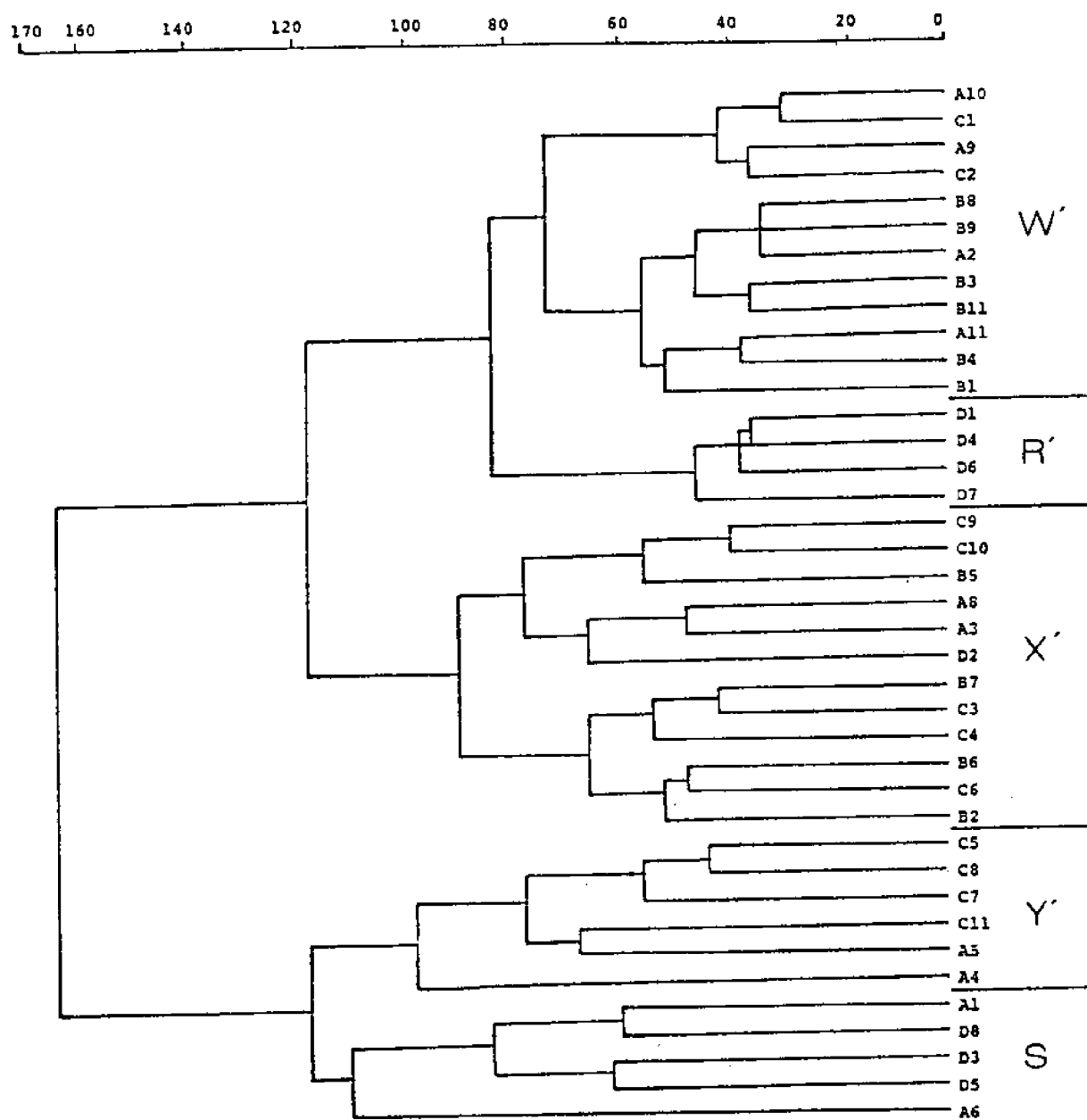


Figure 10. All of the Stations, Biotic Data. August 9, 1973.

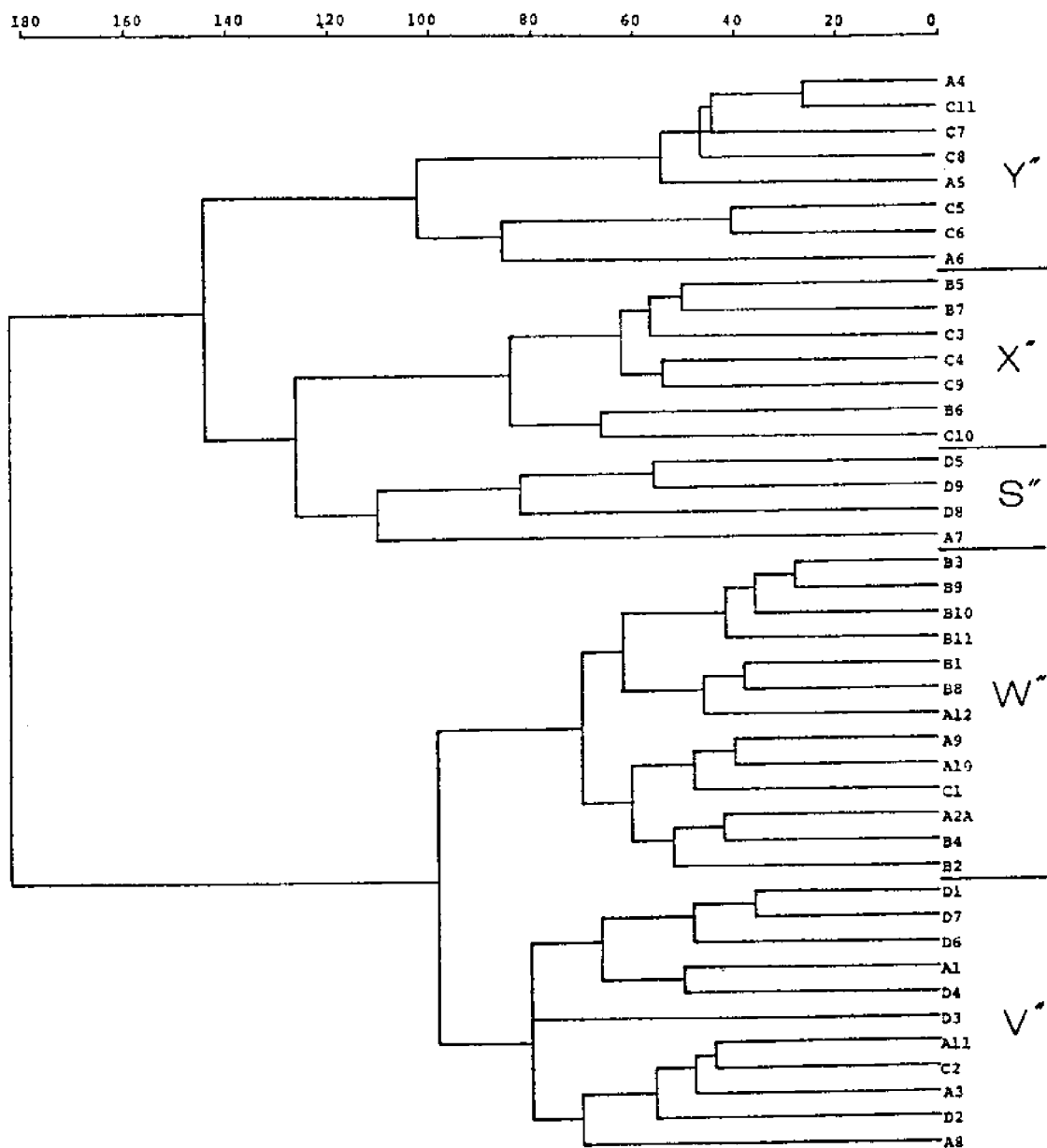


Figure 11. All of the Harbor Benthic Stations. February 11, 1974.

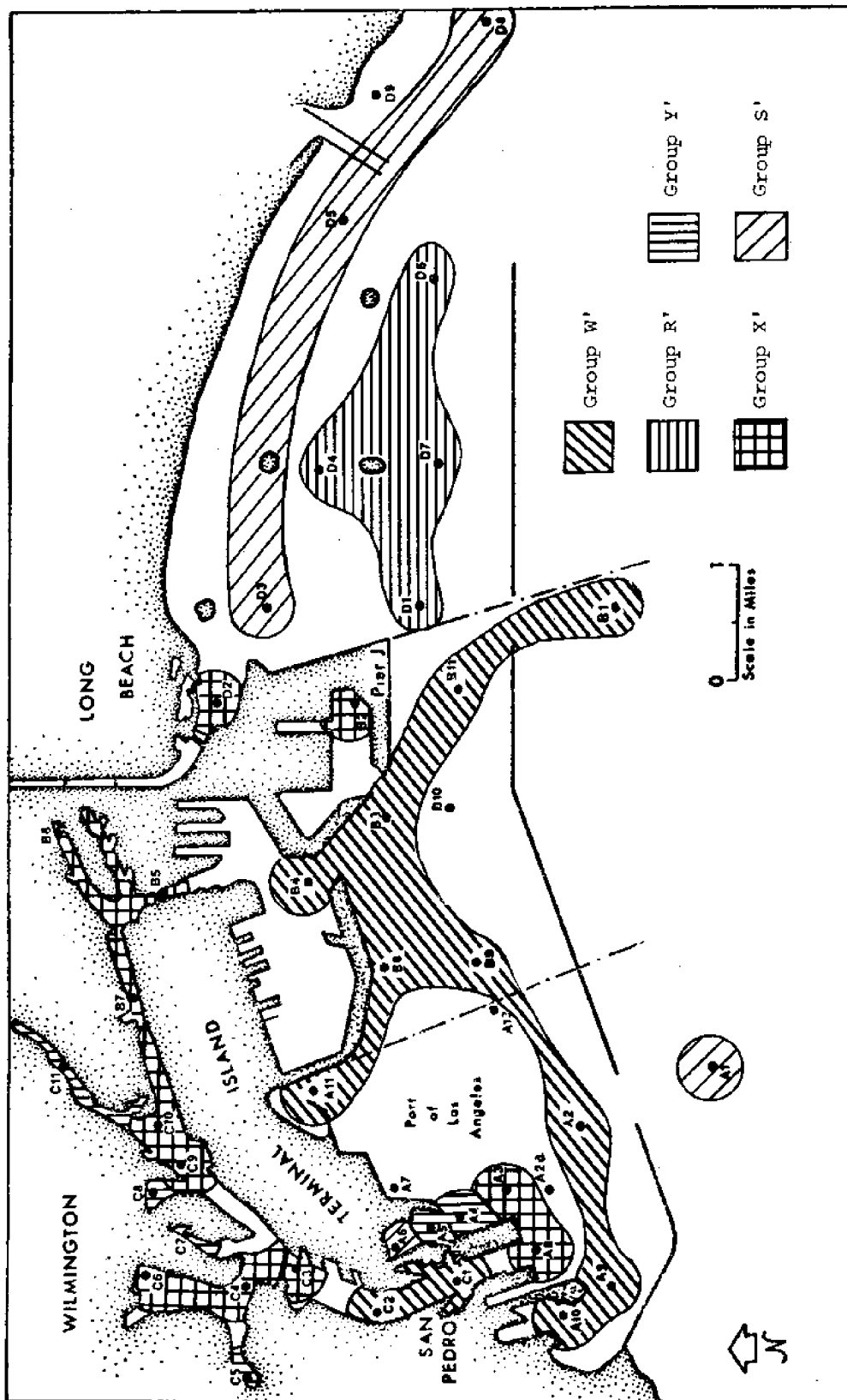


Figure 12. All of the Site Groups, San Pedro Bay. August, 1973.

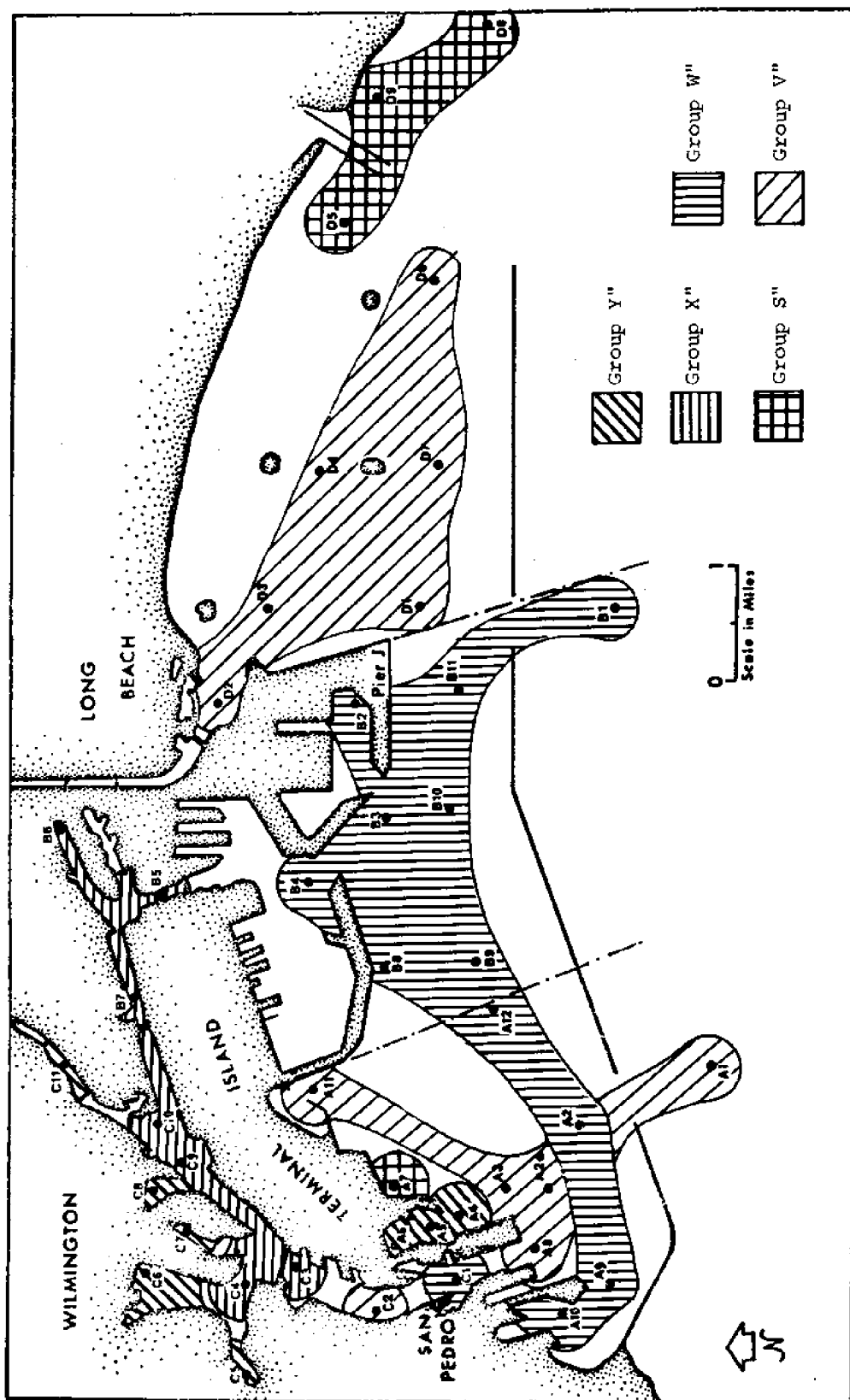


Figure 13. All of the Site Groups, San Pedro Bay. February, 1974.

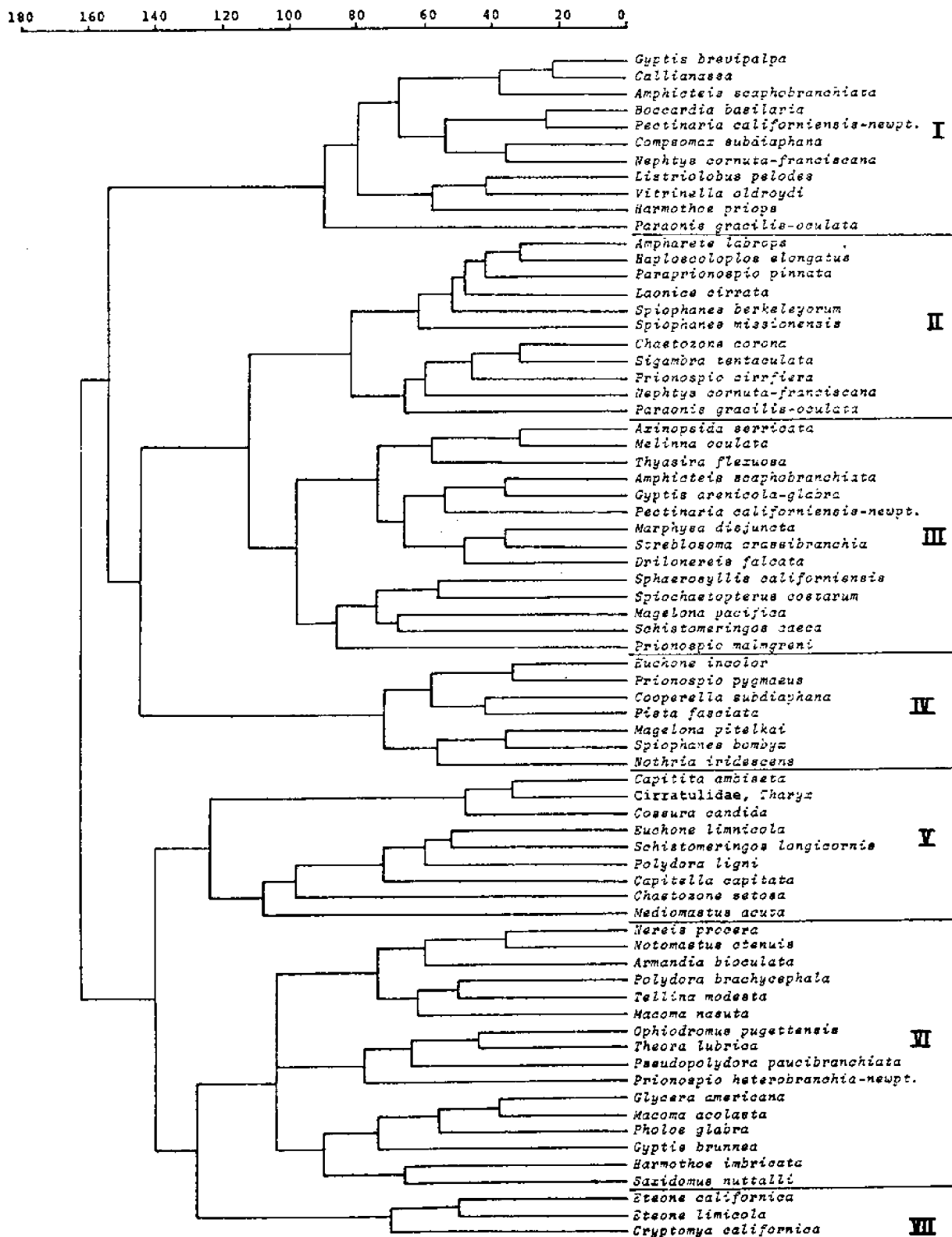


Figure 14. Biotic Data for All Stations. August, 1973.

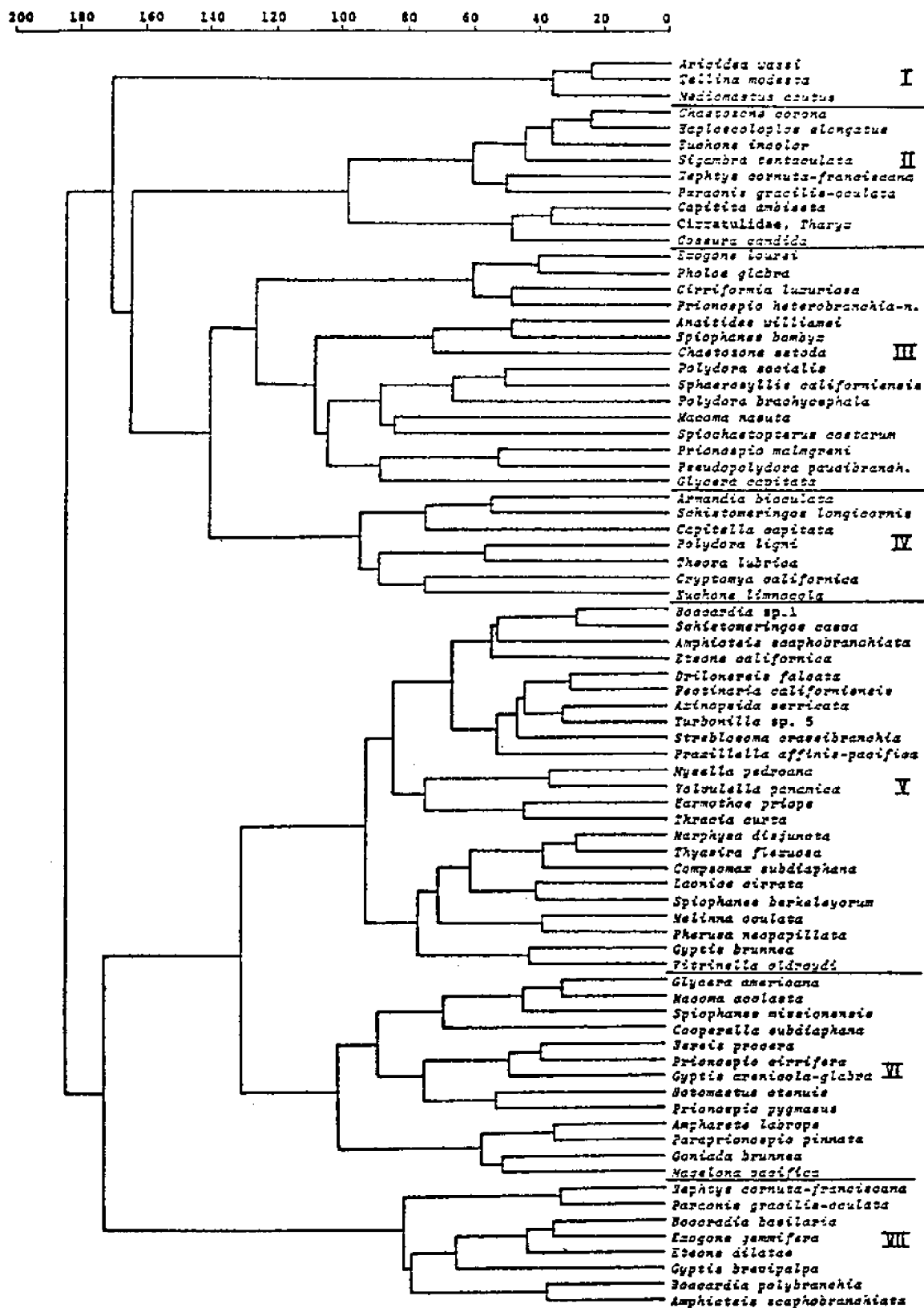


Figure 15. All of the Harbor Benthic Stations. February, 1974.

